EFFECTS OF BANANA WEEVIL AND NEMATODE INFESTATION ON THE GROWTH AND YIELD OF PLANTAIN (*MUSA* AAB) IN GHANA

BY

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ABSTRACT

Banana weevil (*Cosmopolites sordidus* Germar) and nematodes (particularly *Pratylenchus coffeae* [Zimmerman] Filipjev, Schuurmans and Stekhoven), are well known pests of plantain world-wide. An investigation was therefore conducted to quantify yield loss due to the individual and combined infestation of these pests on plantain in Ghana. From the studies on the effects of these pests on plantain using a natural nematode infestation and artificial and natural weevil population, it was concluded that weevil damage to plantain corms caused by the feeding and tunnelling activity of the larvae had serious effect on the vitality of the plants. High densities of *Pratylenchus coffeae* associated with severe necrosis of the roots at flowering and harvest was the cause of a drastic deterioration of both primary and secondary roots. Results however, indicated that, with the occurrence of these two pests a much greater destruction of the corms, primary and secondary roots of the plants was readily expected. Weevil effect thus accounts for the high plant breakage after flowering, failure to reach maturity and a 34.8 % yield reduction. Nematodes effect on the other hand resulted in a complete failure of the majority of plants to flower, a total reduction in the productivity of the mat and a consequent yield loss of 63.7%.. Massive death was the immediate result when the interaction of these pests was pronounced at the early growth stage of the plants, whereas, failure to flower and the inability to reach bunch producing stage was the effect when infestation was delayed. The ultimate effect of this interaction was the drastic reduction in yield of about 85%. On the basis of the present study, the economic importance of these pests whether in combination or occurring separately on plantains in Ghana, cannot be over-emphasised.

DECLARATION

I hereby declare that, except for references to work of other researchers which have been duly cited, this thesis consists entirely of my original research work conducted at the Agricultural Research Station (A.R.S.), Kade, Eastern Region, and that no part of it has been presented for another degree elsewhere.

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DEDICATION

This project is dedicated to my Almighty God and parents, Mr. Leonard Udzu and Mrs. Salomey Kudjo as well as my beloved daughter Emelda Udzu.

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CHAPTER ONE

INTRODUCTION

Plantain is one of the most important food crops for approximately 70 million people in sub-Saharan Africa (Swennen, 1990). In West and Central Africa, where one of the world's highest demographic growth rate occurs, and there is a downward trend in per capita food production, plantain is particularly important (INIBAP, 1992). It is estimated that approximately 60% of the world's total production and consumption of plantain occurs in this region with the bulk of the crop produced on small-scale farms (INIBAP, 1992). In addition to providing food for the people, plantain also generates income for rural and urban dwellers (I.I.T.A, 1993).

Plantain represents an important component of farming systems in the sub-Saharan African region. The crop plays a vital role in protecting the soil from direct insolation and rain impact by virtue of its broad leaf area and extensive root systems (INIBAP, 1992). In Ghana, where plantains rank second to cassava in terms of production and consumption, the crop contributes about 9% of Agricultural Gross Domestic Product (P.P.M.E.D, 1991). In addition, the wide spacing of 3 x 2 m between individual stands, permits intercropping with vegetables such as garden eggs, pepper and cocoyams which in addition to providing vitamins to balance the largely carbohydrate diets, also serve as an assurance of food availability in case of crop failure (P.P.M.E.D, 1991).

Despite the benefits derived from plantain cultivation, there has been a steady decline in production over the past two decades in Ghana. The crop has thus failed to keep pace with the current population growth at the rate of 3% per annum (Hemeng *et al.*, 1996). Records indicate that whilst 1.4 million tonnes were produced in 1985, only 1 million tonnes were recorded in 1989 (Afreh-Nuamah and Hemeng , 1991).

This low level of production has been attributed to several factors such as decreasing soil fertility, partly as a result of increased land pressure linked to rising population, and the increasing incidence and severity of a devastating pest complex comprising banana weevils, nematodes and black sigatoka (Gold, *et al.*, 1991; Akomeah *et al.*, 1995).

Among the many problems associated with plantain production in Ghana, the incidence of pests (banana weevil and nematodes) and diseases (black sigatoka) predominates. These together with the constraints mentioned above have resulted in serious yield losses and accelerated plantation decline (Afreh-Nuamah and Hemeng, 1993). The banana weevil has for instance, been reported to cause a yield reduction of plantain in Ghana from 25% in the first year to 50 90% in subsequent years (Gorenz, 1963). In addition, a complex of plant parasitic nematodes mostly of the lesion forming species have also been reported in plantain roots in the country (Schill *et al.*, 1996). These nematodes create serious root damage resulting in reduced anchorage and consequent toppling of the plant (Sikora and Schloesser, 1973). The banana weevils and nematodes more often than not, occur together and their combined damage leads to increased root and corm destruction, a rapid reduction in plant vigour and provision of entry points for pathogens (Pasberg-Gauhl and Gauhl, 1996).

In response to the decreasing yield of plantain and shortened cropping cycles, there is therefore, the need to investigate the importance of these pests on plantain production in Ghana and to prioritise their effects with respect to growth and yield before any meaningful control can be adopted. It is against this background that this study was conducted to quantify the individual and combined effects of nematodes and banana weevils on the growth and yield of plantain in Ghana, in order to provide a baseline for development of appropriate IPM strategies.

CHAPTER TWO

LITERATURE REVIEW

2 .1 Origin and botany of the crop

Most cultivated *Musa* are triploids (2n=33) (Purseglove, 1972). Almost completely sterile, they develop fruits by parthenocarpy. The genome of the cultivated species is derived from the diploid wild species, *M. acuminata* (A genome) and *M. balbisiana* (B genome) (Purseglove, 1972). The most important cultivars vary in their genomic composition: dessert banana (AAA), East African highland banana (AAA) and cooking bananas (ABB). Plantains on the other hand, form a botanically well defined subgroup among the *Musa* cultivars of AAB genomic composition (Simmonds, 1966).

According to Simmonds (1966), plantains were thought to have originated in southern India. Hybrid triploids were subsequently introduced from the coastal areas of this country to central Malaysia where *Musa acuminata* cultivars (AA and AAA) were developed and grown (Purseglove, 1972). As a result of a long history of cultivation, however, the variation in West and Central Africa far exceeds that found in Asia (Swennen, 1988). This indicates that Africa is now a secondary centre of diversity for plantain (Swennen and Vuylsteke, 1990).

Plantain is basically a large perennial herbaceous plant comprising an underground stem known as the bulb, corm or rhizome. This bulb bears eyes on its middle and upper parts which develop into suckers. Up until flowering, it sends out a large number of roots which, more often than not, remain in the top 30 cm layer of the soil (Skinner, 1987). The inflorescence is a complex spike with each flower having its own basal bract. The cluster of flowers or hands are also protected by a common bract. On emergence, the inflorescence remains briefly in an erect position and later bends over to assume a vertical position.

The fruits are slender, angular, pointed and contain an orange-yellow pulp which remains starchy at maturity. The compound sepal of the flowers also has a typical orange-yellow colour (Simmonds, 1966)

2.2 Plantain types and cropping systems in Ghana

Plantains may be classified into three major types according to their degree of inflorescence degeneration; French, False-horn, and True-horn (INIBAB, 1990). According to Skinner (1987) and Swennen (1990), the French plantain cultivars are distinguished by the fact that they have a large number of hands (6-10) which comprise numerous rather small fingers. The inflorescence is complete and the male part is always large and persistent at maturity. The false-horn plantains on the other hand, have a small number of hands. The bunch is incomplete with no male inflorescence. The true horn plantains usually have only between one and three hands. Their fingers are very long and often very fat but there are very few of them. The inflorescence is also complete. The major cultivars grown in Ghana are shown in Table 2.1.1 below.

Table 2.1.1 Commonly grown plantain cultivars in Ghana

Group	Cultivars
French plantains	Osabum, Nyeretia, Apem Apem-Pa and Oniaba
False-horn plantains	Borodewuio, Apantu-pa, Abomienu, Borodesibor, Aowin
	Nyeretia Apantu, Osoboaso
True-horn plantains	Asamienu, Asamiensa, and Sakoro

Source : Ahiekpor, 1996.

In Ghana, plantain is grown in mixed cropping systems with root crops, cereals and vegetables (Afreh-Nuamah and Hemeng, 1993). In most cases, plantains are the dominant crop (Ahiekpor, 1996). In the majority of food crop production systems, however, maize and the various vegetables are often planted first after the land is cleared, followed by plantains and cocoyams (Afreh-Nuamah and Hemeng, 1993). Plantains are also cultivated intensively in compound gardens where effective management results in good crop production for many years because soil fertility is maintained at a high level and weeds suppressed, due to the application of household refuse and animal waste (INIBAB, 1992).

2.3 Economic Importance of plantain production

Plantains are starchy food crops which make up one-quarter of the total world production of *Musa* spp. (Swennen, 1990). In Africa, where almost 50% of the total world output of plantain is produced, less than 2% of this volume is exported. This demonstrates that the crop is more important as a food crop and for generation of local income than it is as an export commodity (Vuylsteke and Swennen, 1991). In West and Central Africa, where approximately two-thirds and one-fifth of the total African output of plantain is produced respectively, about 70 million people are estimated to derive more than one quarter of their food energy requirement from plantains. Thus making the crop one of the most important sources of dietary carbohydrate in the sub-region (Swennen 1990).

Unlike the sweet bananas, plantains are a staple food which are fried, baked, boiled and then sometimes pounded or roasted, and consumed alone or together with other food (Swennen, 1990) Plantains are extremely rich in vitamin A (INIBAP, 1992). In addition to its uses as food, plantains also serve as feed for livestock; both the leaves and fruit peels are used for this purpose (INIBAP, 1992). In certain parts of the Volta region in Ghana, rejected immature or over-ripened fruits are fed to animals. Fibres obtained from the pseudostems are also used as ropes and doormats (Akomeah *et al.*, 1995). The leaves are used as roofing

materials as well as wrappings for certain local food such as Kenkey (*Fante dorkono*).

According to Gold *et al.* (1993), plantains and bananas are major components of sustainable agricultural systems in densely populated high rainfall areas. As a subsistence crop, plantains are environmentally benign and on steep slopes they reduce soil erosion and provide a mulch for maintaining and improving soil fertility (INIBAP, 1986). Their labour requirements are low and their nutritional value is high (INIBAP, 1986). Moreover, compared to other staples such as cassava, rice and yam, plantains and bananas are the most economical source of carbohydrates in terms of production costs per hectare, per tonne, and per calorie (Swennen, 1990). Although less versatile than the major cereals, they can nevertheless be grown in a range of environments with medium to high rainfall, both upland and lowland. Plantains lend themselves well to intercropping systems and to mixed farming with livestock (INIBAP, 1992).

Plantain is often sold in the local market and the proceeds serve as a source of income for the rural and urban dwellers (I.I.T.A, 1993). In most eco-regions, the fruits are available all year-round and an extended harvesting period coupled with the cultivation of a number of varieties ensures continuous food and an income supply for resource-poor farmers throughout the year (Pasberg-Gauhl and Gauhl, 1996).

In Ghana, plantains serve as food for over 60% of the population (Akomeah *et al.*, 1995). The total land area cropped to plantain is about 129,000 ha with an annual national yield of 7.1 t/ha making it second to cassava in importance (P.P.M.E.D, 1991). Consequently plantain contributes about 9% of Agricultural Gross Domestic Product for Ghana whose per capita consumption of 83 kg per head is higher than maize and is only exceeded by cassava (P.P.M.E D, 1991). The crop is so important that it is grown extensively throughout the forest zone of the country. It is also found in backyard gardens in almost every village, town and city. It has also been found growing along the coastal areas, the dry areas of the

North, and clearings in the high ever-green rain forest (Afreh-Nuamah and Hemeng, 1993). The bulk of the crop is, however, grown in the southern parts of the country where rainfall is about 1500 mm per annum with an annual water deficit below 400 mm (Ahiekpor, 1996). The breakdown of the plantain production in Ghana is shown in the table below.

Table 2.3.1 Quantity of plantain produced in the various regions of the Ghana

Region	Land Area (hectares)	Yield (tonnes)	Yield (tonnes/hectare)
Ashanti	50,940	346,410	6.8
Eastern	39,200	325,000	8.3
Western	31,000	208,000	6.2
Brong-Ahafo	24,700	135,800	5.5
Central	6,600	36,940	5.5
Volta	4,600	29,820	6.5

Source : Akomeah *et al.* (1995).

2.4 Constraints to plantain production

Just like many tropical food crops, plantain production has been affected by certain constraints which have led to diminishing yields and decreasing crop cycles. In much of West Africa for instance, plantain is now treated as an annual crop whereas previously it was ratooned for 25 years or more (Gold *et al.*, 1993). Primary production constraints include decreasing soil fertility due to short fallow periods resulting from increasing population pressure, the use of local varieties of low yield potential (Karikari, 1971; INIBAP, 1986), an inadequate supply of

healthy planting material, post-harvest losses, poor crop and soil management practices (Hemeng *et al.*, 1996), and pests and diseases (Akomeah *et al.*, 1995).

The greatest threat to plantain production is the prevalence of pest and disease pressure which has been increasing over the past 15 years (I.I.T.A, 1996). The most important fungal disease is black sigatoka (Persley and De Langhe, 1987) while banana weevils and nematodes represent the most important pests (Gold *et al.*, 1993)

2.4.1 Black sigatoka

This is a leaf spot disease (also known as black leaf streak) caused by the fungus *Mycosphaerella fijiensis* Morelet var. *deformis*. First identified in Fiji, the disease was accidentally introduced into Southern Africa in the 1970's (Raemakers, 1975), and spread rapidly first in Central and West Africa (Wilson and Budenhagen, 1990), and later to East Africa (I.I.T.A, 1996). Once established the pathogen causes severe leaf necrosis reducing yield of plantain between 20 50% (Pasberg-Gauhl, 1993). All plantain cultivars in West and Central Africa are susceptible to the fungus (Vuylsteke and Swennen, 1993).

The control of this disease has been possible through the extensive use of fungicides such as Tilt^R, Bavistin^R, and Bayfidan^R According to Sery (1993), this practise is very expensive and only feasible in large scale-banana producing countries where the crop is produced for export. Presently the production and cultivation of resistant varieties of plantain is being considered as the most appropriate strategy to manage this disease (Vuylsteke and Swennen, 1991).

2.4.2 Banana weevil: *Cosmopolites sordidus* (Coleoptera Curculionidae)

Cosmopolites sordidus Germar is a native to the Indo-Malaysian regions and possibly to Indonesia (Zimmerman, 1968). It is a serious pest in most *Musa*

growing areas of the world (Haarer, 1964; Wolfenberger, 1964; Purseglove, 1972; INIBAP, 1988), particularly of cooking bananas (Sikora *et al.*, 1989) and plantains (Jones, 1986).

The insect is pantropical in distribution and appears to have been spread with the cultivation of bananas (Allard *et al.*, 1991). In the Caribbean region, Florida, and Central America, crop losses due to this pest range between 30-90% in heavily infested areas (Pena *et al.*, 1993). In East Africa, this insect has been reported to be a major pest on bananas (Harris, 1947), especially in Tanzania (Bujulu *et al* ., 1985) and Uganda (McNutt, 1972). It has also been recognized as a serious pest of bananas in Australia (Froggat, 1925; Braithwaite, 1958).

2.4.2.1 Biology of the weevil

The female lays eggs singly in cavities made with the mouth parts (rostrum). This takes place mostly at night. The most favoured laying site is between the sheath scars on the crown of the plantain corm just above the ground or at the base of the pseudostem (Frogatt, 1925; McNutt,1972). Females have a low multiplication rate intensity of 0.2 - 2.4 eggs / female / month according to Frogatt (1925), and up to 12 (Koppenhoffer, 1993). Egg deposition is continued almost until the death of female but the number tends to be greater in early life compared with later life (Frogatt, 1925)

The length of the reproductive life cycle varies according to the environmental conditions but lasts for an average of two months (Viswanath, 1977). The time that elapses between egg deposition and the emergence of the larvae shows a wide variation under different climatic conditions such as are experienced with the changing seasons (Frogatt, 1925). In spring and autumn in temperate regions, the average is about 8 days but the period could extend to over 30 days and in some cases has fallen to about 4 days in the summer (Frogatt, 1925). Afreh-Nuamah (1993) reported that the larval stage lasts for about 21 days and develops into the pupa which takes 6 - 8 days to mature into an adult. Newly

emerged adults are first brownish in colour but turn black after about 14 days (Frogatt, 1925).

2.4.2.2 Life history of the weevil

Adult weevils are dark, about 11-12 mm long, hard shelled, and have a pronounced snout. They are sluggish in nature and feign death if disturbed (Woodruff, 1969; Treverrow, 1985). The weevil has a long life span (up to 2 years) and a low natural mortality (Koppenhofer, 1991).

Adults are active mainly at night and feed on plant materials at various stages of decomposition, such as rotten corms and pieces of pseudostem. They are markedly hygrophilous and thigmotactic (Viswanath, 1977). All four stages of the weevil are associated with the banana plant and are present throughout the year (Treverrow, 1985). Their population dynamics according to Viswanath (1977) and Afreh-Nuamah (1993), depend on the climatic conditions. In Ghana, the emergence of adult weevils reaches a peak during the rainy season from August to September and again in the early part of November. Between December and March however, there is a reduction in the population when the drought is at its peak (Afreh-Nuamah, 1993).

Their markedly sedentary behaviour (Whalley, 1957) coupled with their longevity and the ability of the adults to fast for long periods of time, enables survival when conditions are unfavourable (Lemnaire, 1996). The most preferred habitat of the weevil according to Vilardebo (1984), is the stump together with the pseudostem from the stages of flowering to the emergence of younger suckers.

2.4.2.3 Damage caused by the banana weevil

Adult weevils cause negligible damage and feed mainly on rotten banana tissues (Froggat, 1924; Franzman, 1972; Budenburg and Ndiege, 1993). The larvae are responsible for all the damage caused to the plant (Harris, 1947; Franzman, 1972).

After hatching from the egg, the larvae tunnel and feed on the tissue of the rhizome destroying the central cylinder (with the vascular bundles) thus leading to the breakdown of physiological communication between the aerial shoot and underground stem (Froggat, 1924; Franzman,1972). This process interferes with nutrient uptake and transport to the aerial portions of the plant resulting in weakening, and a reduction in bunch weight (Franzman, 1972; Treverrow, 1985). In serious cases (when the entire corm is completely riddled), the plant snaps (falls over) at the ground level before the bunch is ripe (Franzman,1972; Budenburg and Ndiege, 1993; Pena *et al.*, 1993).

Extensive tunnelling by the larvae also interferes with root initiation as a result of the destruction of the corm's cortical tissue, thus leading to the production of small numbers of roots, which consequently affects anchorage of the plant (Franzman, 1972; Wright, 1977).

Frogatt (1925), reported that, in a heavily infested field the attack of the grub may become so severe that the plants may be killed or fail to flower leading to complete loss of the plant before it has thrown a bunch. In one case recorded, some plants in an attempt to throw a bunch had only sufficient vigour to develop half the first hand and in odd cases one or two fingers on the second hand. The larvae of the weevil had riddled the butts and travelled up to 1 m up the stems in many of these plants (Frogatt, 1925).

The larvae is also capable of tunnelling from the parent corm into that of the sucker produced from it. Under such conditions, it is not uncommon to find very few suckers produced by the mother plant. Such suckers, tend to be poor and unhealthy and in most cases are characterized by stunted growth (Froggat,1924;

Franzman, 1972). In this way, the availability of healthy suckers for propagation is tremendously affected (Frogatt 1925). This is another serious effect of the borer as the continued prosperity of a plantation depends on the growth of healthy plants.

Newly planted suckers in heavily infested fields are also readily destroyed soon after planting as the larvae traverse the entire length of such plants from the central core of the bulb to the in-folding leaf (Froggat, 1924; Ostmark, 1974). According to Froggat (1924) most of these suckers when pulled out, snapped off about three inches above the ground, often exposing a grub, and exhibiting a complete internal riddling.

During unfavourable growth periods, when the plants are striving against adverse conditions, the effect of the borer tends to undermine the remaining vitality of the plant, leading to more or less complete breakdown of the stool far more rapidly than would occur in a normal or good season (Frogatt, 1925; Yaringano and Van der Meer, 1978; Treverrow, 1985).

By preventing the plants from forming and storing the amount of nutrients required, not only to maintain them in full vigour but also to produce the best quality of fruit possible per bunch, the banana weevil causes a very considerable reduction of profits to the farmer (Frogatt, 1925). Rukazambuga (1996) for instance reported that, severe attack by the borer could have a drastic effect on growth of plantain resulting in bunch weight decrease and a consequent yield reduction of up to 85%. In Ghana, it is estimated that yield reduction due to banana weevil infestation is about 25% for the first crop and 50-90% in the subsequent years (Gorenz, 1963).

2.4.2.4 Host range

The banana weevil *Cosmopolites sordidus* is specific to *Musa* (Frogatt 1925; Hord and Flippin, 1956; Viswanath, 1977) and attacks all varieties of the

crop (Hord and Flippin, 1956). It has also been found on Manila hemp, sugar cane and even on yam. It appears however, to be a very minor pest of the latter two, perhaps attacking them only when bananas and plantains are not available (Hord and Filppin, 1956). The presence of adults has also been recorded on sweet potato and Canna corms lifted near infested banana plantations (Frogatt, 1925).

For host preference among *Musa* species, plantains of genome AAB are the most attractive and most damaged by the borer whiles banana of genome AAA are the least, with ABB Bluggoes intermediate between the two (Price, 1993). A more precise study based on the peripheral corm damage assessment devised by Vilardebo (1973), has shown that the species *Musa acuminata* Colla., is more susceptible than *Musa balbisiana* Colla. and that the plantain AAB group are always severely attacked (Simmonds, 1966).

2.4.2.5 Control measures

Control measures involving the use of chemicals like carbofuran (Furadan^{R} 10 G), Primicid^{R} (pirimiphos-ethyl, ICI), Dursban^{R}, Terracur P ^{R} (fensulfothion, Bayer), Kepone^{R} (chordecone, Allied chemicals), Oftanol^{R} (isophenphos, Bayer) have widely been adopted by large scale banana producers in Latin America and the Caribbean (Pullen, 1973), Uganda (Allard *et al.*, 1991). The prohibitive cost of these chemicals coupled with their hazardous effect on the environment, the farmer, as well as the prospective consumer, and the development of resistance by the weevils, have recently increased the interest in non-insecticidal control (Treverrow and Maddox, 1988).

Among the non-insecticidal control techniques, the widely adopted one is effective cultural practice involving the use of clean planting materials (prepared by paring to remove traces of larvae tunnels and potential egg infested sites or hot water treatment) in a clean field.

Biological control that has been tested includes the use of predaceous ants such as *Tretamorium* spp., *Pheidole megacephala* Fabricius, *P. guineense*

Fabricius, *Azteca delpini* Emery, *Ectatomma ruidum* Roger, *Solenopsis geminata* Fabricius, *Wasmannia auropunctata* Mayr and *P. fallax* Mayr (Kermarrec *et al.*, 1993). Enthomopathogenic nematodes such as *Steinernema spp.* and *Heterorhabditis* sp. (HT2-Trinidad strain) (Kermarrec *et al.*, 1993) are also being investigated.

In addition, entomopathogenic fungi *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin (Pena *et al.*, 1993), and certain Histerids (*Plaesius javanus* Erickson and *Hololepta quadridentata* Fabricius), as well as Hydrophilidae (*Dactylosternum hydrophiloides* Macelay, *D. abdominale* Fabricius) are currently being advocated as future potential control agents capable of reducing the pest status of the weevil.

2.4.3 Nematodes

Nematodes are microscopic worms which live in the soil and infest plant roots. With a few exceptions plant nematodes are not highly specific with regard to the plants on which they feed. A host list, however, tends to be long and to include plants in widely divergent groups (Christie, 1959).

Several types of nematodes can extensively damage plantain and banana root systems if they are introduced with infested planting materials (Swennen, 1990). According to Bridge (1991), some plant parasitic nematodes of *Musa* have a widespread distribution, while others, have a more restricted spread in the main banana and plantain growing areas of the world. The most common species of nematodes known to cause serious damage to *Musa* spp. are: *Radopholus similis* (Cobb) Thorne; *Pratylenchus coffeae* (Zimmerman) Filipjev, Schuurmans and Stekhoven; *Pratylenchus goodeyi* Sher and Allen and *Helicotylenchus multicinctus* (Cobb) Golden. Other nematodes which are potentially important are *Meloidogyne* spp., *Rotylenchus reinformis* Linford and Oliveira; *Hoplolaimus pararobustus* (Schuurmans, Stekhoven and Tevinssen) Sher; *Helicotylenchus*

microcephalus Sher; *H. macronatus* Siddiqi and *Zygotylenchus taomasinae* (de Guiran) Brawn and Loof (Bridge 1991; Coosemans 1991).

Among the nematodes encountered on plantains and bananas in most *Musa* production areas, the burrowing nematode - *Radopholus similis* is reported to be the most important and destructive (Blake, 1969). The root knot nematode *Meloidogyne* spp. although, widely distributed in banana plantations, is usually considered as minor pest.

2.4.3.1 *Radopholus similis.*

Wehunt and Edwards (1968) gave a list of countries where *R. similis* has been found on bananas and plantains. For instance in Southern Africa, estimated crop loss caused by this nematode is 75-80% (Jones, 1979; Jones and Milne 1982). It is widespread in Mozambique and Natal and is present in some farms of Transvaal (Evaristo, 1969). In Eastern Africa, *R. similis* is an important root pathogen of dessert bananas especially in Somalia and Uganda (Ddungu, 1988).

R. similis is also a major economic problem in the Pacific Islands (Bridge, 1993), throughout Central and South America (Stover and Fielding 1958), and the Caribbean Islands (Leach, 1958). In West Africa, *R. similis* is the main nematode species on dessert banana. In Ivory Coast alone, yield loss due to this nematode may reach 30-35% under optimal growing conditions in fertile soils and over 75% where soils are poorly eroded (Sarah 1989).

The pre-adult and adult females of these nematodes puncture the epidermal cells along the entire length of the roots by repeated stylet thrusts. They then enter through the wounds and occupy an intracellular position within the cortex where they feed on the cytoplasm of adjacent cells causing their cell walls to rupture, and the nucleus is either ingested or degenerates. Such cell destruction according to Blake (1972) and Stover (1972), leads to the formation of extensive cavities in the cortex. Folkertsma (1987), reported that severe infestation by *R. simlis* could

lead to toppling or uprooting of the plant. This is when remnants of the root system attached to the corm are pulled out of the ground when the plant falls.

According to Loos and Loos (1960), and Blake (1972), corm-borne infections are of particular significance in the introduction of *R. similis* into new fields or plantations. Since new roots arising from setts after planting do so in the vicinity of pre-existing roots, they are likely to be invaded by nematodes migrating from existing corm infections. *R. similis* may also be disseminated by water that drains from infested areas (Blake, 1972)

2.4.3.2 *Helicotylenchus* spp.

These nematodes are also a widely distributed species in most banana and plantain growing areas of the world (Bridge, 1993). The nematodes are probably the most important causes of serious yield decline of banana in the Jordan valley of Israel (Minz et al., 1960). The species also occurs in Australia (Blake, 1972), Cuba (Wehunt and Edwards. 1968), Ivory Coast (Sarah, 1989), and Honduras (Bridge, 1993). Other nematodes of this genus that have been recorded either from roots or soil around banana plants or both include *H. africanus* in the Canary Islands (Bridge, 1993), *H. dihystera* in Australia and Honduras (Stover and Fielding, 1958), and *H. erythunea* in Ecuador, Costa-Rica and Guatemala (Blake, 1972).

These nematode species penetrate the outer cortical cells causing discolouration and necrosis. In contrast to *R. similis*, *Helicotylenchus* spp. form few cavities in the cortex and histological changes are confined to areas of direct feeding usually parenchyma cells close to the epidermis (Folkertsma, 1987; Blake,1972).

2.4.3.3 *Pratylenchus* spp.

These are another group of nematode species commonly associated with banana and plantains (Blake, 1972). Five species of these root lesion nematodes have been recorded on *Musa*. *P. coffeae* seems to be the most widespread and

there are many reports of this species particularly from plantations in Central America (Wehunt and Edwards, 1968). Both *P. goodeyi* and *P. thornei* have also been reported from the Canary Islands (Blake, 1972), Burundi and Uganda (Bridge, 1988), Egypt (Oteifa, 1962), and Ethiopia (Bridge, 1993).

According to Blake (1972), root lesion nematodes cause lesions similar to, but less extensive than those caused by *R. similis*. The initial entry of the nematodes produces in the root cortex a reddish elongated fleck which enlarges as the nematode and its offspring feed. The older parts of the lesions, however, turn black and shrink while the advancing portions turn red (Blake, 1972).

2.4.3.4 *Meloidogyne* spp.

Root knot nematodes as they are commonly called are obligate sedentary endoparasites frequently found in warm moist and friable soils of banana plantations. Although there are over 50 reported species of *Meloidogyne*, four of them: *M. incognita, M. javanica, M. aveneria,* and *M. hapla* account for about 90% of all populations of root knot nematodes found on cultivated crop plants in agricultural soils (Mai and Abawi, 1987).

These four common species have an extensive host range, including agronomic crops and weeds that belong to many plant families (Hussey, 1985). According to Mai and Abawi (1987), these nematodes are abundant and cause sub-optimal yield losses in light textural soils with good drainage. They have rarely been found in soils with more than 40% clay or 50% silt fractions (Taylor *et al.*, 1982). Worldwide crop losses attributable to root knot nematodes have been estimated at about 5% but larger and more extensive losses have been documented especially on small farms in developing countries (Sasser and Carter, 1985).

According to Mai and Abawi (1987), severely infested plants may appear chlorotic, stunted, necrotic, and/or wilted especially during periods of moisture stress and high temperature. The most common symptoms associated with root knot nematodes is the presence of galls. These galls vary between 1-10 mm in

diameter or smaller, depending on the nematode species involved and the location of galls in the root - system.

Severely galled root systems become malformed with shortened and thickened individual roots which may appear as a mass of galls (Mai and Abawi, 1987). The growth rate of roots as well as root branching are frequently suppressed by infection with root knot nematodes. The altered growth results in reduced root volume and surface area leading to a reduced capacity for water and nutrient uptake. In addition, the synthesis of cytokinins, gibberillins and other growth determining metabolites are also affected (Hussey, 1985).

Histological studies by Bryne *et al.* (1977) and Meon *et al.* (1978) have shown that infection by *Meloidogyne* spp. results in abnormal vessel elements and disruption of the arrangement and continuity of vascular tissues. Hussey (1985), thus suggested that such changes markedly affect water flow in the xylem and disrupts nutrient absorption and translocation. Another study, by Bird and Loveys (1975), showed that giant cells associated with the feeding of these nematodes serve as a nutrient sink Furthermore, infection of roots by root knot nematodes decreases the rate of photosynthesis because of the interference of the production of a photosynthesis regulatory factor in the root tissue (Hussey, 1985).

The loss of yield caused by *Meloidogyne* spp has, however, not been assessed experimentally for bananas, but consensus of opinion is that root-knot nematodes usually do not depress yields significantly (Blake 1972). This is because, the rate at which *Meloidogyne* spp. multiply or reproduce in banana roots is limited in the presence of other nematodes. Since banana roots are rarely attacked by only one nematode species, it is probable that, the necrosis associated with the other nematodes *(Radopholus similis: Helicotylenchus* spp: and *Pratylenchus* spp), would render the root-knot nematodes to be relatively innocuous pathogens (Blake, 1972).

2.4.3.5 Nematode species in Ghana

Lamptey and Karikari (1975) reported that *Helicotylenchus dihystera* and *Meloidogyne* spp. were among the pests which attacked plantains in Ghana. Afreh-Nuamah and Hemeng (1995) also identified *Meloidogyne* spp., *Pratylenchus* spp. *and Helicotylenchus* spp. In a recent survey to assess and characterize constraints to plantain production in Ghana, Schill *et al.* (1996), reported that the dominant nematode species encounted in plantain roots in Ghana were all lesion forming nematodes.

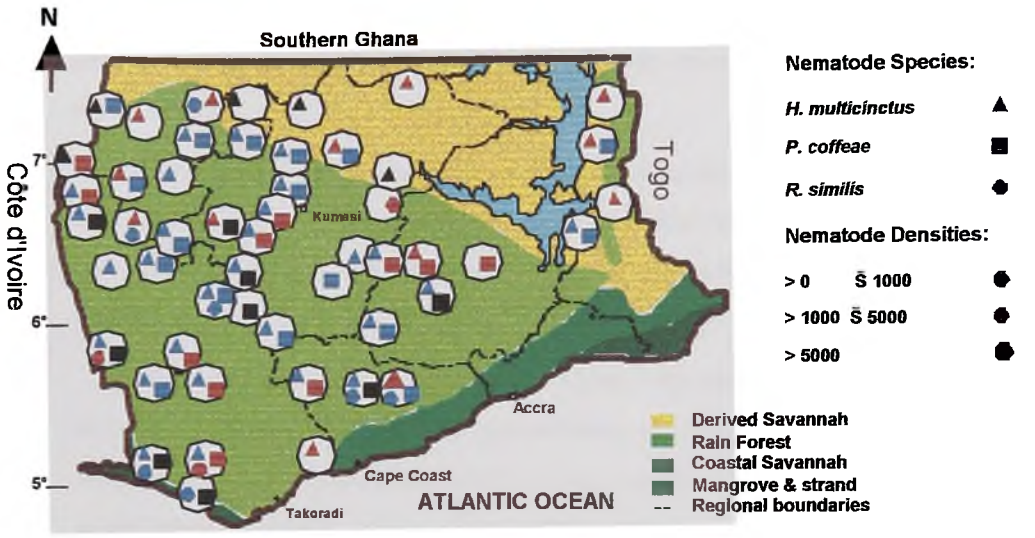
The report revealed that *Pratylenchus coffeae* and *Helicotylenchus multicinctus* were the most wide-spread nematode species, while *R. similis* even though present had a localized occurrence. *Meloidogyne* was also wide-spread but occurred in low densities particularly in the survey area. Figure 2.4.3.5 below shows the distribution of nematodes species and their densities in plantain areas in Ghana according to the survey data of Schill *et al.* (1996).

2.4.3.6. Effect of nematodes on plant growth and yield

All nematodes whether free living or phytophagous, are heterotrophic organisms which are linked to autotrophic organisms for their energy supply. Phytophagous nematodes in general tend to affect plant growth and productivity through their damage to the root system and rhizome (Queneherve, 1993). Because plant parasitic nematodes feed, multiply and migrate in the root (Sarah 1989; Bridge, 1993), the root system is severely decreased and the plant anchorage becomes reduced in the soil (Blake, 1972).

By wounding the host and inducing histological change, nematodes may provide infection sites for other micro-organisms and thereby affect their aetiology, particularly of root diseases (Pitcher, 1965). Newhall (1958), for example, showed that the incidence of Panama wilt (*Fusarium oxysporium* f. sp.) was doubled in the presence of *R. similis* during an experimental period of two months. Secondary infection by fungi has also been reported to enhance the process of root necrosis

Figure 2.4.3.5 Nematode damage and density of lesion forming nematodes on plantain in Ghana (Schill *et al.*, 1996)*



*1. Symbols represent species
2. Colour of symbol represents densities

(Speijer and Sikora, 1993; Speijer *et al.*, 1993). Plants with necrotic roots are less able to take up water and nutrients resulting in stunted growth, reduced bunch size, and delayed maturation time (Speijer *et al.*, 1995). In addition, the size and possibly, the number of leaves and the rate of growth of suckers is also decreased (Blake, 1972).

Severe root necrosis caused by a complex interaction between nematodes and fungi is a major factor leading to reduced productivity of the mat, a shorter reproductive life span and ultimate toppling of the plant (Speijer and Sikora, 1993), especially those carrying a bunch (Stover 1972).

The ultimate effect of continued nematode infestation is to decrease the economic life of plantations from being indefinite to as little as one year, a situation that has come to be regarded as normal in some countries where nematode control is not practiced (Blake, 1972). This results in annual replanting and a drastic increase in cost and / or loss of productivity (Blake, 1972). Plantain according to Swennen and Vuylsteke (1990), are generally less productive than bananas because of their high susceptibility to nematodes.

2.4.3.7 Control measures

Just as mentioned for banana weevils, chemical control has been one of the most effective means of managing nematode populations. Nematicides (chemicals used in controlling nematodes) such as carbofuran (Furadan 5 G^R), Vydate^R (oxamyl), and Nemacur^R (phenamiphos) have been used successfully on large scale banana and plantain fields in Ivory Coast and Cameroon (INIBAP. 1994) as well as Indonesia and the Philippines (Davide, 1994).

Considering the cost and potential environmental hazards associated with chemical control, the use of alternative control measures like introducing and encouraging the growth of the following nematode-trapping fungi has been recommended. These include; *Arthrobotrys oligospora* Fresen, *A. brochopaga*

(Drechsler) Shenk, Kendr, and Pramer (Coosemans, 1993) and *Dactylella ellipsospora* Grove, *D. candida* (Nees), *D. thaumasia* Drechsler (Christie, 1959). The growth of certain plants (*Tagettes* spp. and *Crotalaria* sp.) has also been adopted to reduce nematode populations (Christie, 1959; INIBAP, 1994). Effective cultural control practices involving paring to remove all roots whether nematode infected or not and subsequent heating in hot water at a temperature of 55 °C is also currently being adopted to control the spread of nematodes to newly cultivated fields (Sheshu-Reddy *et al.*, 1993).

2.4.4 Weevil and nematode interaction

In many instances, the banana weevil and nematodes occur together and their combined damage interferes with nutrient uptake and transport, resulting in slow growth, reduced bunch size, reduced fruit filling, and increased susceptibility to wind lodging (Bridge and Gowen, 1993; Afreh-Nuamah, 1993). The extensive tunnelling and discolouration of the rhizome by the banana weevil larvae coupled with the severe root necrosis due to the activities of a complex of plant parasitic nematodes, more often than not, give the plant an appearance of debility and the readiness to fall over under wind action (Pena *et al.*, 1993)

Nematode damage may enhance banana weevil infestation to the extent that, nematode infested suckers are four times more prone to weevil damage than suckers without nematodes (Speijer *et al.*, 1994). Consequently, the accumulation and combination of banana weevil and nematodes thus become major problems in plantain production and more so, in older fields (I.I.T.A, 1996).

In Ghana, the key biotic constraints to plantain production include banana weevil (*Cosmopolites sordidus*), banana nematode complex (*Pratylenchus* spp and others), and black sigatoka (Afreh-Nuamah 1993; Akomeah *et al.*, 1995; Schill *et al.*, 1996). Although, the combined effect of these pests and diseases clearly affect yield (Pasberg-Gauhl and Gauhl, 1996), losses have not been properly quantified nor partitioned among such constraints.

It is against this background that the present work was conducted to

1. quantify yield loss of plantain due to infestation by

a) banana weevil

b) nematodes

c) banana weevil and nematodes

2. evaluate the effect of

a) banana weevil

b) nematodes

c) banana weevil and nematodes on the growth and establishment of plantain.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

Details of the general materials and methods that are common to several experiments are presented below, whereas specific details relating to individual experiments are described in the appropriate chapter.

3.1 Weevil trapping

Weevils required for subsequent experiments were collected from farmers' fields with traps of at least 10 cm thick and 15 cm long cut from spent plantain pseudostems (Ogenga-Latigo and Bakyalire, 1993). Single traps were placed at the bases of the mother plants with the flat length-wise portions on the soil surface. The thicker basal part of the stem was always used because it had the ability to remain moist for long periods of time. Weevils collected from the traps were taken to the laboratory, separated into males and females according to the structure of the last abdominal sternite and counted (Roth and Willis, 1963).

3.2 Weevil damage assessment

Weevil damage assessment was done by making two transverse cross-sectional cuts on the corms of harvested plants at 0 and 5 cm below the pseudostem/rhizome interface. These cuts exposed two areas in the corm (an inner and outer) which were easily distinguished by colour. The diameter of the corm at these levels was measured and the area of portions with weevil galleries was expressed as a percentage of the total area of the corm cross-section assessed (Gold *et al.*, 1994). The percentage corm damage obtained at each level (0 and 5 cm below the pseudostem/rhizome inter-face) was averaged for each plant.

3.3 Nematode extraction, identification, and counting

Nematodes in plantain root samples were extracted using the modified Baermann's technique (Jacobs and Bezooijen, 1984). This technique involved using a plastic container filled with approximately 100 ml of tap water. A sieve with a diameter of 15 cm was placed in this dish. The sieves were locally made by sectioning a 12 cm long plastic pipe into small rings. The mesh of the sieve was made of mosquito nylon netting, which was glued to the 2 cm wide plastic ring of the pipe. The sieve rested on 0.5 cm high supports and contained one layer of Kleenex^{R} facial tissue paper.

Approximately 5 g of the roots was macerated in 200 ml water with an electric blender before pouring onto a sieve. The macerated roots in the sieve were incubated for 24 h at a room temperature of 25° C. The nematodes collected in the dish were poured into 400 ml plastic cups and stored in the fridge (4^{0}C) prior to counting. After a minimum period of 20 min to allow the nematodes to settle, the volume of the suspension in the 400 ml cups was reduced to 25 ml (or 100 ml in case a very high density of nematodes was suspected). The suspension was thoroughly stirred with air from an aquarium pump (Speijer, 1993). Three sub-samples of 1 ml were taken from the 25 or 100 ml solution with a micro-pipette and the nematode species in each were identified and counted using a counting slide with the aid of a compound microscope (Kashaija *et al.*, 1994).

3.4 Treatment of planting materials

Before planting, suckers were first pared by removing roots and the immediate outer layer of the corms to a depth of approximately 0.3 cm and treated in hot water at a temperature of 55°C for 20 min to eliminate weevils and nematodes (Colbran, 1967; Sheshu-Reddy *et al.*, 1993). The hot water treatment involved immersing the pared plantain suckers in heated water that had attained a constant temperature (55° C) contained in a tank measuring 1 m x 1 m x 1.5 m. Heat was supplied from a 60 kg cylinder of propane gas through a regulator with a

hose and a 10 cm diameter heating burner. Two wire baskets each measuring 70 cm x 37.5 cm. x 52.5 cm held the planting materials, in order that they would not come into contact with the side of the hot water tank (Colbran, 1967).

3.5 Statistical analyses

ANOVA was performed on all the data in order to analyse the effect of treatments on growth and yield parameters. Prior to subjecting these data to ANOVA, those involving counts such as number of weevils and number of nematodes were transformed with the square root (f) scale. Data in percentages were also transformed using the Arcsin (x). The Duncan's Multiple Range Test (DMRT) was used to separate the means after the ANOVA. The probability level used was 5 %. Linear regression was carried out to obtain the relationship between yield and each of the following: total number of roots, and necrotic index in functional roots both at flowering and harvest.

CHAPTER FOUR

EFFECT OF GROWTH STAGE OF PLANTAIN ON WEEVIL DAMAGE

4.1 Experiment 1: Monitoring banana weevil populations and their associated damage on plantains at their various stages of growth on selected farmers' fields

4.1.1 Introduction

The level of banana weevil infestation on plantain in relation to damage caused, is an important factor to consider in any experiment involving the artificial introduction of the pest onto individual plants. Although Afreh-Nuamah (1993) reported that weevil infestation of plantain fields was negligible in the first year, additional information on the level of weevil infestation per plant and the associated damage at different growth stages was, however, needed to determine damage thresholds.

It is against this background that prior to the main field trial (Chapter 5) involving artificial inoculation of plantain with banana weevils, this preliminary experiment was conducted, to monitor the weevil population on individual plants in selected farmers' fields from planting to maturity.

4.1.2 Materials and methods

4.1.2.1 Selection of experimental sites

With the support of an extension officer, seven large-scale plantain production areas were selected in the Eastern region of Ghana. Five of these, namely the villages of Akanteng, Apinaman, Dwenase, Asuom, and Pramkese, were chosen for the experiment based on ease of accessibility, willingness of the

farmers to co-operate, and the availability of at least two plantain farms that fell within each of the age categories required for the experiment (that is 1-5 months after planting, 6 months after planting flowering, and first week of flowering harvest). At the end of the survey, two fields within each age category were chosen in each of the villages for the trial.

4.1.2.2 Trap setting and inspection

The experiment was conducted for a duration of 15 weeks. In the first 5 weeks, weevils were trapped and collected as described in Section 3.1 on the fields between 1-5 months old (two fields per village). On each field, a single trap was placed at the base of each of 36 plants. In the next 5 weeks, the same number of traps, was used on the fields with plants aged between 6 months after planting and flowering, and in the last 5 weeks, the traps were set on the fields with plants between flowering and harvesting. Traps were set on Mondays and Thursdays of each week and weevils were collected 3 days later. Only the number of female weevils was counted because they lay the eggs whose larvae are responsible for the damage on plantain corms (Harris, 1947; Franzman, 1972; Treverrow, 1985). At the end of weevil collection for a particular experimental farm, four plants were randomly selected for weevil damage assessment (Section 3.2).

4.1.3 RESULTS

The mean number of female banana weevils trapped from plantain at different growth stages is shown in Table 4.1.3.1 (Appendix 1). Except for Akanteng the other villages did not show significant differences in the numbers of weevils collected. It was also observed that, the mean number of weevils associated with the plants at the initial growth stage (1 5 months after planting), was significantly lower than those encountered on plants between 6 months and flowering, and from flowering to harvest. Weevil counts on plants between 6

months to flowering and those between flowering to harvest were however not significantly different.

Table 4.1.3.1 Mean number of female weevils collected per plant at the various stages of plant growth in 5 villages

Village	Growth stages			
	1 - 5 months after planting	6 months after planting -flowering	Flowering-harvest	Mean
Akanteng	0.7	2.4	3.6	2.23a
Apinaman	0.4	2.1	2.8	1.77ab
Dwenase	0.4	2.0	2.3	1.57b
Asoum	0.2	1.8	2.1	1.37b
Pramkese	0.3	2.7	2.6	1.87b
Mean	0.40b	2.20a	2.68a	

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$)

Table 4 1 3.2 shows the percentage corm damage due to weevils observed on the plants at the various growth stages. Corm damage increased from 6 months after planting until harvest with plants at their early stage of growth being significantly less damaged than the later stages (Appendix 2).

Table 4.1.3.2 Percent corm damage due to weevils at various growth stage of plantain in 5 villages

Village	Growth stages			
	1 - 5 months after planting	6 months after planting -flowering	Flowering-harvest	Mean
Akanteng	4.05	16.25	39.00	19.77a
Apinaman	1.55	8.00	28.75	12.77b
Dwenase	1.90	9.00	26.00	12.30b
Asoum	0.70	2.50	25.50	9.57b
Pramkese	1.80	12.00	23.50	12.43b
Mean	2.00a	9.55b	28.55c	

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$) performed on transformed data.

The data suggests some form of positive association between number of female weevils and corm damage It was also evident that weevil infestation and corm damage commences at the early growth stage but becomes increasingly higher as the plants grow and approach harvest.

4.1.4 Discussion

Results indicate that more weevils were encountered at the post-flowering than the pre-flowering phase of the crop. This could most probably be due to population build-up over time. Secondly, the older plants by virture of their broad leaves and large amount of leaf sheaths may have been more attractive to the highly hygrophilous, nocturnal and thigmotactic banana weevils because such plants provided enough shade and shelter at their bases to protect these insects from sun and desiccation (Rukazambuga *et al*., 1991: Lemnaire, 1996). Younger plants on the other hand were associated with low weevil numbers because their corms were buried in the soil thus, making them less accessible to the banana weevil for egg laying and feeding (Ittyeipe. 1986). In addition, such plants did not have the shade providing characteristics such as pertained to the older plants. The above findings are in agreement with Ostmark (1974) who reported that banana borers do not usually attack corms until they are nearly mature.

The higher weevil infestation associated with plants at the post-flowering phase might have accounted for the significantly higher corm damage associated with on these plants. The higher corm damage might have also resulted from the large surface area associated with older plants which enable them to support high population of eggs and larvae (Ittyeipe, 1986). The higher percentage damage according to Ittyeipe, (1986) could have resulted from a cumulative measure of borer damage on the plant from the time of infestation to the time when the damage assessment was done. Furthermore, female weevils prefer old corms to young corms for feeding and egg laying (INIBAP, 1994) since the former is softer. This pre-supposes that some female weevils already present in the fields could go into reproductive diapause and not lay any eggs until such plants attained the right stage of growth to induce infestation and egg laying.

Larger amount of leaf sheaths, broader leaves and larger corm surface areas, and the readily exposed corm parts, were some of the characteristics of plantain that were observed to enhance weevil infestation. Since these characteristics were found on plants between 6 months and above, an artificial infestation of plantains at this stage of growth would be justified.

Although, the results showed that high weevil numbers could lead to a relatively high corm damage (approximately 39 %) on the older plants, there was the need to investigate the effect of a higher infestation on the early stages of growth.

4.2 Experiment 2: Pot trial to evaluate the effect of weevil infestation on the initial growth stage of plantain (from planting to 3 months)

4.2.1 Introduction

Weevil infestation on plantain occurs at all growth stages of the crop from planting to maturity (Experiment 1). In Ghana, however, the assessment of damage on the corm or rhizome associated with weevil infestation is mostly done at the time of harvest or on toppled or snapped plants (Afreh-Nuamah, 1993; Schill *et al*, 1996). Hence, most of the literature (Gorenz, 1963; Afreh-Nuamah, 1993 ; Akomeah *et al*., 1995; Schill *et al*., 1996) on the effect of this pest on plantain in the country is restricted to the older stages of growth of the plant. Thus a study to investigate the effects of its infestation on crop development from 1 to 3 months after planting was considered necessary. This trial provided additional information on the critical period of weevil infestation on the young plants (suckers) which was vital for the establishment of the yield loss experiment (Chapter 5).

4.2.2 Materials and methods

4.2.2.1 Experimental design

A completely randomised design was used to test 6 treatment combinations :

Time of weevil infestation	
Months after planting (MAP)	Presence (w+) / Absence (w-)
1	+
1	
2	+
2	
3	+
3	

For treatments at 1 MAP, there were 10 plants per replicate, compared with 16 plants per replicate and 20 plants per replicate at 2 and 3 MAP respectively, giving 92 plants in total. The difference in replication was due to unavailability of weevils at the early stage in the experiment. Effect of time of weevil infestation on corm damage and plant growth parameters was analysed using one way ANOVA.

4.2.2.2 Soil acquisition and sterilisation

Sandy loam soil used in conducting the trial was dug from the forest about 5 km from the Research Station. The soil was sterilised at a temperature of 57°C for 20 min. This was done by pouring the soil (40 l volume of it at a time) into a metal drum of approximately 1.5 m high which was placed on a 76 x 47 x 76 cm metal frame, of approximately 65 cm high above a wood fire maintained under the drum (Speijer, 1993).

One hundred plastic buckets of 25 l capacity were each filled to a volume of 23.5 l with sterilised sandy loam soil. A little space was left on top of the plastic

buckets for mulching with cut stubble of *Chromolaena odorata* to provide shade for the banana weevils.

4.2.2.3 Planting of suckers and weevil introduction

100 suckers of the local plantain cultivar Apantu-Pa obtained from farmers' fields and treated according to Section 3.4 were planted in the sterilised soil in individual plastic buckets. A week after planting, 92 of these buckets (20 for the first, 32 for the second, and 40 for the third months) with plants of uniform growth were selected for the trial. Ten weevils (5 males and 5 females) per plant were released into each of the weevil treated pots at 1, 2 or 3 months after planting. Banana weevils collected according to Section 3.1 were used in this trial. Shortly after artificially infesting the plants with the weevils, they were mulched and later covered with 0.8 m^2 mosquito nylon netting to prevent the weevils from escaping.

4.2.2.4 Plant maintenance

Two weeks after planting, Urea (46% N), single super-phosphate and muriate of potash fertilisers were applied at the rate of 5 g per plant. This rate was derived from the recommended dosage for matured plants (Obeifuna and Onyele, 1985). The plants were placed on raised platforms of 2 m above the ground to prevent re-infestation by weevils and nematodes contained in splashed soils. The plants were watered every other day.

4.2.2.5 Harvesting of test plants

Test plants were sampled approximately 31 days after weevil introduction. At sampling, the plants were cut at 10 cm from the soil level, nylon netting taken off, mulch removed, plants turned upside down and the contents poured into a large basin containing water. The roots were cleared of soil particles with water from a running tap and later cut from the corms, counted, and their fresh weight

determined. Banana weevil damage assessment was done as described in Section 3.2. This time the assessments were done at 3 and 5 cm below the pseudostem /rhizome interface because of the small size of the sucker.

4.2.3. RESULTS

At the time of harvest all the plants infested with weevils had died. Death of these plants was preceded by stunted growth followed by the development of yellowish green withered leaves. Table 4.2.3.1.(Appendix 3) shows the effect of weevil infestation on the number of roots of plantain at their initial growth stage. It was observed that the untreated (w-) plants produced more roots than the treated (w+) ones in each of the three months.

Table 4.2.3.1. Number of roots of plantain cultivar Apantu Pa harvested 31 days after infestation with banana weevil one, two, or three months after planting

Treatment combination					
Month 1		Month 2		Month 3	
w+	w-	w+	w-	w+	w-
7.4d	10.0c	10.6c	14.4b	15.1b	22.6a

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$)

Table 4.2.3.2 (Appendix 4) shows the mean weight of roots of plantain obtained from the various treatments. The results indicate that, for a particular time of infestation roots produced by the control (w-) were heavier than those from infested (w+) plants. Consequently, the means of the untreated plants were therefore significantly different from those of the weevil treated ones in the respective months.

Table 4.2.3.2. Fresh root weight (g) of plantain cultivar Apantu-Pa harvested at 31 days after infestation with banana weevil one, two, or three months after planting

Treatment combination					
Month 1		Month 2		Month 3	
w+	w-	w+	w-	w+	w-
15.7e	26.6d	40.4c	59.4b	48.1c	80.27a

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$)

Corm diameter as shown in Table 4.2.3.3 (Appendix 5), increased with increasing age of the plants. For plants infested I MAP, the mean corm diameter of control did not differ significantly from those produced by the weevil infested treatment. For plants infested 2 or 3, MAP however, significantly larger corms were produced by the control plants. The results indicates that corm diameter was significantly affected by the presence of weevil and their time of attack

Table 4.2.3.3. Corm diameter (cm) of plantain harvested 31 days after infestation with banana weevil one, two, or three months after planting

Treatment combination					
Month 1		Month 2		Month 3	
w+	w-	w+	w-	w+	w-
7.4d	8.5bc	8.0cd	9.3ab	8.6bc	10.1a

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$).

Table 4.2.3.4 (Appendix 6) shows that corm damage on all the uninfested plants was negligible. On the infested corms however, time of infestation had a significant effect with greatest damage at month 1 compared to months 2 and 3.

Table 4.2.3.4 Percentage corm damage of plantain harvested 31 days after infestation with banana weevil, one, two, or three months after planting

Treatment combination					
Month 1		Month 2		Month 3	
w+	w-	w+	w-	w+	w-
83.0a	0 0d	66.0b	0.0d	48.0c	0.0d

Means followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$) performed on transformed data.

4.2.4 Discussion

Results from experiment 2 show that in the absence of weevil attack, roots of plantain suckers grew vigorously in number and weight. On the other hand, the presence of this pest was observed to have a deteriorating effect on development of the roots as a result of increased corm damage. The relatively small size of the infested corms might have contributed to the increased corm damage of the infested suckers as the central part of such corms were readily accessible to the borer (Ittyeipe, 1986) whose voracious feeding consumed and subsequently cut through many root origins causing the affected roots to die (Froggat, 1924: Franzman, 1972).

Secondly, the stored food which had to be drawn on and used up, to provide the necessary materials for the development of fresh root tissues was also reduced by the extensive feeding on the rhizome by the borer (Froggat, 1924). This indicates that roots produced by infested corms would be comparatively smaller in number than those produced by uninfested corms. Wright (1977) also reported that weevil damage on young plants (suckers), besides affecting root emergence, also retarded the establishment and survival of already emerged ones. This could have accounted for the significantly lower fresh weights of the roots obtained from the infested plants.

The stunted nature and eventual death of the infested plants observed during the experiment, might have resulted from a reduction or complete cut-off of the translocation of photosynthates from the leaves to the basal parts of the plants as well as the flow of nutrients in the opposite direction. According to Froggat (1925) and Haarer (1964), this can occur due to the complete breakdown of the physiological communication between the leaves and the basal portion of the plant, caused by the feeding and tunnelling activity of the larvae.

This trial confirmed that growth and development of plantain suckers measured by the number and fresh weight of roots as well as the health status of the corm, could be affected adversely 1 - 3 months after planting in the presence of banana weevil.

Moreover, growth could be more adversely affected if the suckers were infested as early as one month after planting (INIBAP, 1994).

Since weevil infestation (according to experiment 1) could start as early as 1 month after planting on a field previously cropped to plantain, the release of 5 female weevils per plant one month after planting in the yield loss trial would have been justified. Experiment 2, however, indicated that, the presence of 10 weevils (5 females and 5 males) per plant at the earlier stage of growth (1-3 months after planting) under appropriate conditions, could also lead to total crop failure. From these two experiments therefore, it was decided that artificial weevil infestation of the plants in the yield loss experiment should be made 6 months after planting using 5 females and 5 male weevils. This was most appropriate because plants at that growth stage had all the characteristics that could keep the weevils and enhance their attack as discussed in experiment 1.

CHAPTER FIVE

EFFECT OF BANANA WEEVIL AND NEMATODE INFESTATION ON THE GROWTH AND YIELD OF PLANTAIN

5.1 Experiment 1: Preliminary study to determine the residual population of banana weevils and nematodes on experimental plots

5.1.1 Introduction

According to Wallace, (1937), Nanne and Klink, (1975), the residual plantain plant after the bunch is harvested, which is made up of the spent stem (pseudostem) and the true stem (corm or rhizome) serves as the sole breeding site for weevils. Blake (1972) also reported that residual nematodes are also encountered on the roots of suckers as well as the corms of harvested plants. The field to be used for the yields loss trial (Section 5.2) had been previously cropped with plantain. Due to this previous cropping, a greater number of pseudostems on the field had decayed leaving traces of the true stem, most of which were apparently in the decomposition stage, with a few of them supporting unthrifty peepers, sword, and maiden suckers. It was therefore necessary to determine the extent of infestation and population level of nematodes (from the soil and roots of young suckers) as well as weevils, before the establishment of the yield loss experiment.

5.1.2 Materials and methods

5.1.2.1 Weevil trapping and collection

Fifty pseudostem traps were set at the bases of residual plants on the experimental plots, selected at random (this was changed after every two weeks) as described in Section 3.1. The weevils were collected and counted at fortnightly intervals for 4 months.

5.1.2.2 Collecting root and soil samples for nematode extraction

For nematodes, both root and soil samples were collected to determine density and species. Prior to root and soil sample collection, the field was cleared manually and divided into four blocks containing four plots each. Soil samples were taken from a depth of 10-25 cm at 25 locations selected at random for each plot. Root samples were, however, collected from the ratoons available. Nematodes were extracted from the samples, identified and counted as described in Section 3.3.

5.1.3 RESULTS

5.1.3.1: Nematode species and their densities in root and soil samples

The nematode species and their corresponding numbers encountered in root samples taken from the field is indicated in Tables 5.3.1.1 (1).

Table 5.1.3.1(1) Densities of various nematode species per 100g root samples collected on the field

Nematode species	Replicate 1	2	3	4	Mean
Pratylenchus coffeae	3313	2625	3063	4625	3406
Helicotylenchus multicinctus	292	250	438	438	354
Paratylenchus sp.	396	0	188	63	161
Meloidogyne spp.	563	625	500	313	500
Radopholus similis	0	21	0	0	5

Five nematodes species were found in the root samples. The dominant nematode species observed were *Pratylenchus coffeae* (4625 / 100 g in one sample), *Helicotylenchus multicinctus,* and *Meloidogyne spp.* Even though *Radopholus similis* was encountered its density was very low.

The densities of the different nematode species found in the soil samples are shown in Table 5.1.3.1 (2). Nematodes of the two genera *Hoplolaimus* and *Dorylaimus* were encountered in all the soil samples taken from the field.

Table 5.1.3.1(2) Density and types of nematodes per 100 g soil sample collected from the field

	Replicate				
Nematode species.	1	2	3	4	Mean
Pratylenchus coffeae	14	25	6	0	11
Helicotylenchus multicinctus	25	13	0	0	9
Hoplolaimus sp.	261	344	297	318	305
Dorylaimus sp.	172	416	380	266	308

A greater proportion of these nematodes were made up of the L2 juvenile stages. Unlike the root samples, the numbers of *P. coffeae* and *H. multicinctus* observed in the soil samples were very low. From these results, it was concluded that the population of nematodes in the field were sufficiently high to conduct the yield loss experiment without the need for artificial inoculation.

5.1.3.2 Number of weevils trapped on the corms of harvested plants with their ratoons.

The numbers of male and female weevils collected is shown in the Table 5.1.3.2 (1). More females than males were trapped over the experimental period.

Table 5.1.3.2 (1) Residual population of weevils in the field plot prior to planting the experiment

	SAMPLE NUMBER *								
SEX	1	2	3	4	5	6	7	8	Total
Male	66	72	73	71	40	42	33	27	424
Female	72	70	69	71	45	49	39	37	452

* Collected at fortnightly intervals

Average trap catches decreased with time. This was probably because the weevils collected were not returned to the field. These results showed that the field was infested with weevils. The presence of weevil larvae observed in the residual material when it was dug out, showed that the weevil borer was able to use the rotting material as food even in the absence of healthy corms or rhizomes. Nevertheless, it was concluded that the residual population was very low in comparison to weevil numbers recorded on-farm where weevil damage had been observed (Section 4.1.3). Thus artificial infestation was necessary in order to enhance weevil activity in the field.

5.1.4 Discussion

Previously cropped fields with traces of residual and fallen plants could be major sources of weevil population build up as shown in this experiment. Treverrow and Maddock (1988) also confirmed this finding. The presence of some larvae observed in the residual material when it was dug out show that the weevil borer could persist in the field for some time before declining in number. Since it has also been shown by other reports (Wallace, 1937; Nanne and Klink, 1975) that residual corm materials are important source of infestation, crop hygiene such as the complete removal of spent corms together with pseudostems can be adopted as the first control measure to clean up a previously infested field before any new planting can be done (Treverrow and Maddock, 1988). Similarly, the presence of the nematodes particularly *Pratylenchus coffeae* could mean that, they were also capable of remaining and multiplying in the roots of the suckers after the parent plant is harvested and this could also serve as an inoculum source. The high number of nematodes encountered might be due to the fact that these nematodes were not only present in the residual plants but in the soil as well as in some weeds, particularly *Chromolaena odorata* which can serve as a host to them (Brentu, 1999). Thus, implying that clean suckers which are planted in such fields stand the chance of being infested (INIBAP, 1994).

5.2 Experiment 2: Field evaluation of the effect of banana weevil and nematodes on the growth and yield of plantain

5.2.1 Introduction

Banana weevils and nematodes are considered as very important pests of plantain in Africa (Skinner, 1987). According to Bridge and Gowen (1991), these

pests occur together and are associated with similar gross symptoms of damage such as poor growth, reduced bunch weight and toppling. In Ghana, Afreh-Nuamah (1991 and 1993), Afreh-Nuamah and Hemeng (1995) Akomeah *et al.* (1995) and Schill *et al.* (1996) have commented on the importance of these pests in the production of plantain in the country. The relative importance of banana weevil and nematodes is however, unclear in most plantain production zones in Ghana. It is against this background that the field trial was conducted to investigate the effect of banana weevil and nematode infestation on the growth and yield of plantain.

5.2.2 Materials and methods

5.2.2.1 Experimental site

The experiment was conducted at the Agricultural Research Station (A.R.S) Kade in the Eastern region of Ghana on a previously cropped plantain field whose soil type was sandy loam and had a residual population of nematodes and weevils as presented in Section 5.1.3. On the immediate right of the field was an abandoned field of plantain intercropped with cassava (5 m away from plot) and on the immediate left was an abandoned pepper field (5 m away from plot). The experimental plot had a unidirectional systematic gradient and covered an area of 3750 m^2 (50 m x 75 m).

The effect of weevils was studied using artificial inoculum augmented by the natural population while the effect of nematodes was studied using natural infestation.

5.2.2.2 Experimental treatment and design

Each of 4 treatments below were replicated four times and set up in a randomised complete block design. There were 16 plots with 25 data plants spaced at 3 m by 2 m in each plot. Each plot was surrounded by border plants.

The four treatments evaluated were:

1). Effect of banana weevils (W+): The plants that received this treatment were each artificially infested with 10 banana weevils (5 males and 5 females) six months after planting. Weevils were collected from farmers' fields as described in Section 3.1. The natural population of weevils was, however, not controlled. Nematodes on plots under this treatment were controlled. The first nematicide application was done after land clearing (3 weeks before planting) by sprinkling 30 g Nemacur 10 GR^{R} (phenamiphos; Bayer) on 1 m^2 area of land around positions where individual suckers were to be planted. A second application was effected at planting using Nemacur^{R} 400 EC (phenamiphos; Bayer) at the rate of 5 ml / plant (that is 8.3 l/ha). Thereafter, the plants were treated every four months

2). Effect of Nematodes (N+); All residual plantain corms remaining on plots that received this treatment were dug out with a spade immediately after assigning treatments to the various plots. This was done to ensure that such plots were completely free from banana weevil infestation. In addition each plant under this treatment was treated with a systemic insecticide Oftanol^{R} 500 EC (isophenphos; Bayer) at the rate of 5 mls / litre of water per plant (that is 8.3 l/ha). The first application was done 1 month after planting and afterwards repeated every 4 months until harvest, as recommended by the manufacturer. Nematodes identified earlier on such plots were not controlled and were thus allowed to infest the plants.

3). Effect of banana weevil and nematodes (WN+); No pesticide was applied on plots under this treatment. In addition, banana weevils were artificially introduced onto the plants as described for W+ treatment.

4). Effect of controlled weevil and nematodes (WN-); Both weevils and nematodes on plots under this treatment were controlled routinely (that is at 4

monthly intervals) by the application of Oftanol [R] and Nemacur [R] at the rates specified above.

5.2.2.3 Field preparation and planting

Prior to planting, the field was cleared manually, stubble collected and dumped at the edges. The field was then divided into 4 blocks of 4 plots each. Samples of soil were dug with an auger as mentioned in Section 3.3 and taken to the laboratory where the nematode numbers and species were determined as in Section 3.3. Treatments were later assigned at random to the plots, for each block. The false horn local plantain cultivar (Apantu-Pa) obtained from farmers' fields were used as planting material. This cultivar was preferred to others because of its early maturing characteristics (Hotsonyame, 1991). These suckers were treated as mentioned in Section 3.1 after which they were kept in a secured cool dry airy place for 24 h to prevent weevil contact and fungal infection before planting.

5.2.2.4 Weevil collection and artificial infestation

Banana weevils used for the artificial infestation were collected from farmers' fields as described in Section 3.1. Ten weevils (five males and five females) were placed at the bases of each plant on plots that received the W+ and WN+ treatments six months after planting.

5.2.2.5 Maintenance of the plants

For effective maintenance of the plants, three split doses of urea (46% N), single super phosphate (S.O.S), and muriate of potash (M.O.P) fertilisers were applied (by broadcasting the S.O.S and M.O.P and burying the urea within a 50 cm radius from the plant) at the rates of 120 g, 100 g, 150 g respectively, based on data from fertiliser trials at the Research Station. Because the land had previously been

cropped to plantain and was not left to fallow for a sufficient period of time before conducting this experiment, the fertilisers were applied as a booster (Ahiekpor, pers. comm.). Times of application were 1, 3, and 7 months after planting. Black sigatoka was controlled by the application of a systemic fungicide Bayfidan^{R} (Bayer) at the rate of 3.31 l/ha, 1 month after planting and thereafter repeated at 6 monthly intervals. Weeding was done manually once every 2 weeks

5.2.2.6 Data collected

Monthly measurements of the following parameters, to determine the effect of the treatment on growth and morphology of the plants, were recorded for all data plants from 3 months after planting until flowering :

1). **Plant height** . A graduated pole of 260 cm tall was placed at the base of the plant. The height in cm from the soil level to the point of intersection between the two highest petioles was recorded.

2). **Number of leaves**: All functional leaves from the youngest opened leaf to the oldest were counted. Dead leaves were, however, ignored.

3). **Plant girth**. Pseudostem girth in cm was measured at 1 m above ground with a measuring tape.

The following data in addition to (1), (2), and (3) were also collected at flowering to determine treatment effects on reproduction:

4). Date of flowering expressed in days and fixed on the day on which the first bract enveloping the inflorescence appeared completely at the top of the pseudostem.

5). Number of different types of suckers (peepers, sword, and maiden) attached to the plant.

6). Height of the tallest sucker

7). Number of leaves of the tallest sucker.

8). Number of roots in 20 x 20 x 20 cm^3 volume of soil dug from an area extending outward from the corm (Speijer *et al.*, 1994).

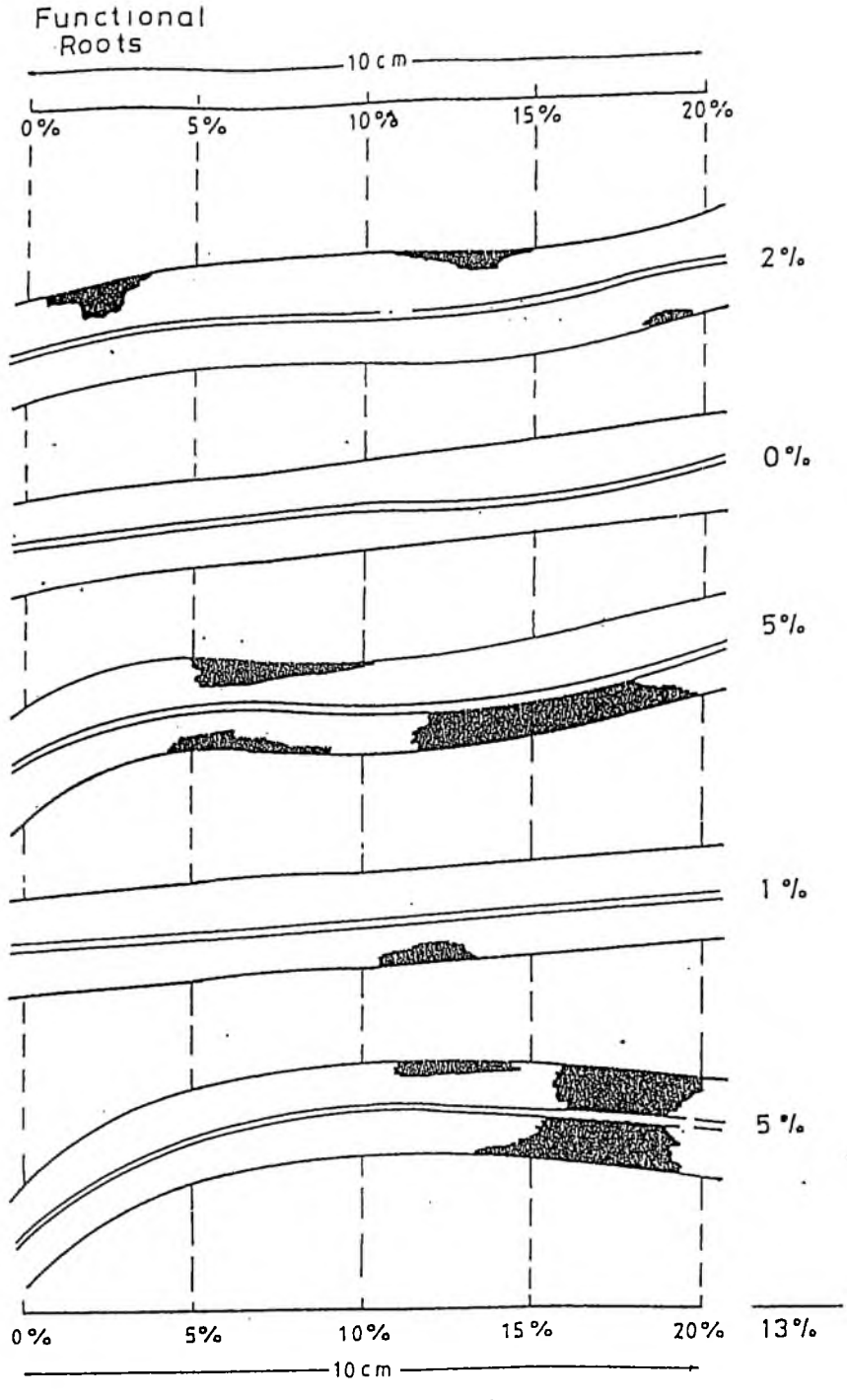
9). Length and width of the seventh youngest leaf. The seventh leaf was chosen because it is assumed to represent the average area of all the leaves on the plant (Schill, pers. comm.).

The following data was also collected from each data plant at flowering using the procedure devised by Speijer and Gold (1996) to monitor nematode effects on the plant.

10). Percentage dead roots: The number of dead roots which were completely rotten or shrivelled was expressed as a percentage of the number of the roots obtained from 20 cm^3 volume of soil.

11). Percentage functional roots: A similar procedure as described in (10) was conducted but this time functional roots (roots showing at least some healthy tissue) were counted.

12). Root health assessment: Five primary roots were selected at random from each plant, cut into 10 cm lengths, and sliced longitudinally into two halves (that is 10 root pieces). One half, which was represented by 5 root pieces, was scored for root necrosis by expressing the damaged portion as a percentage of the total area occupied by the cortex (see Figure 5.2.2.6 (1))



5·2·2·6 (1)

Figure A score for root necrosis in the cortex of five length-wise sliced segments of functional primary roots.

13). Health assessment of all the feeder roots was made according to the procedure recommended by Speijer (1993).

Root status	Scale
All healthy	1
More healthy	2
More dead	3
All dead	4

14). Presence or absence of root galls

15). Nematode density in roots. Nematodes were extracted, identified and counted from functional roots as described in Section 3.3.

16). Monitoring of the weevil population. This was done 1 month after weevil introduction and involved setting single traps separately on 15 randomly selected plants from each plot as described in Section 3.1 and counting the number of weevils three days thereafter. The weevils were released onto the plants after counting.

At harvest the following data were recorded to determine treatment effects on yield:

17) Date of harvesting in days from the time of planting

18). Number of functional leaves

19). Number of suckers

20). Height of tallest sucker

21). Number of leaves of tallest sucker

22). Bunch weight using a hanging scale

23) Number of hands

24). Number of fingers per bunch

25). Length, width and weight of the middle finger from each hand.

At harvest root health assessment was conducted on the youngest sucker because the mother plants at that time of growth do not produce assimilates to enhance further root growth and development. Nematode activities thus become reduced in such plants and are instead directed towards the roots of the vigorous growing youngest sucker on the mother plant (Speijer and Gold, 1996).

26). Number of roots (functional and dead) of the youngest sucker (less than 50 cm tall) attached to the mother plant. Prior to the counting, the sucker was detached carefully from the mother plant with a spade and cleared free of the soil attached to its surface. Two slits of 180^0 apart were made on the rhizome of the sucker (the part bearing roots) and all the roots found within this periphery were then counted and recorded The suckers were thinly peeled afterwards and examined for nematode lesions and the extent of necrosis according to the following method described by Speijer and De Waele (1997). See Table 5.2.2 4(1)

Table 5.2.2.6 (1) Assessment of nematode damage on corms of the youngest sucker

Score	Degree of necrosis	Lesion condition in root cortex or index peeled sucker surface
0	No necrosis	No lesions visible
1	Very light necrosis	One small lesion visible
2	Light necrosis	Several small lesions visible
3	Moderate necrosis	One, large lesion visible
4	Severe necrosis	Several large lesions visible

A lesion was defined as a small lesion when its diameter was less than the cortex diameter of the associated root in the sucker. A large lesion was described as such when the lesion was equal or larger than the diameter of the cortex of the associated root. The health status of the roots of the youngest suckers were also measured as described in (11), (12), and (13) and (14). Nematode types and species in the youngest suckers were also determined as described in (15) above.

27). At harvest the presence or absence of weevil damage on the youngest sucker was also determined as shown in Table 5.2.2.6 (2).

Table 5.2.2.6(2) Severity of weevil damage on plantain suckers

Description of damage	Scale
Damage absent	0
Slight damage of < 1 cm diameter	1
Severe damage of more > 1 cm diameter	2

28) Weevil damage assessment on the mother plant

After the removal of the sucker, the whole corm of the mother plant was dug out from the soil as carefully as possible. The corm was thinly peeled to expose weevil tunnels. Weevil damage assessment were carried out on two portions of the corm; the outer or peripheral and inner cross-sectional (transverse) surfaces. Damage on the outer surface was assessed 5 - 10 cm from the pseudostem / rhizome

interface using a suitable semi-circular wooden template divided into 10 segments. The portions within each segment with weevil galleries were expressed as a percentage of the total area occupied by that segment and the value was recorded on a segmental basis. Each segment was given a value of 10%. Hence a maximum value of 100% was obtained if the portion within all of the segments was completely covered by weevil galleries. The percentage damage in each segment was added up to give the total peripheral damage of the corm (Gold *et al.*, 1994) The cross-sectional damage was assessed as described in Section 3.2.

5.3 RESULTS

5.3.1. Effect of weevils and nematodes on the number of plants reaching maturity

At the time of flowering, it was observed that some of the data plants were of the wrong cultivars; these plants were excluded from data collection. In addition, plants showing symptoms of virus (cucumber mosaic virus and banana streak virus) were uprooted. Analysis of variance ($P < 0.05$; Appendix 7) showed that the percentage of plants that reached maturity was significantly higher in the control than the other treatments. It was also observed that whereas the effects of the separate infestations by weevils and nematodes significantly reduced the percentage of plants that reached maturity from 97% to 71% and 47% respectively, the effect of the combined nematode and weevil infestation further reduced the percentage to 23.8% (Table 5.3.1.1).

The combined weevil and nematode treatment gave the highest percentage of plants dead (44 %) all death occurred before flowering. In most cases death was preceded by stunting of the plants followed by drying of the pseudostems and the development of yellowish-green withered leaves. Attempts made at uprooting some of the dead plants resulted in the snapping of such plants at the pseudostem / rhizome interface. Occasionally, one or two weevil larvae and in some cases, newly emerged adults were encountered in the corms of these plants.

A high percentage of plants (44 %) (Table 5.3.1.1) failed to flower in the sole nematode treatment. This phenomenon was also observed for 28.6 % plants in the WN+. In particular, for one plot infested with weevils and nematodes none of the plants reached maturity. On this particular plot as well as on the other weevil and nematode treated plots, most of the plants were stunted and the rest were dead. For the weevil only treatment, the majority of plants reached maturity, although approximately a quarter of the plants were either broken or failed to flower.

Table 5.3.1.1 Effect of treatments on the mean percentage of plants reaching maturity

Plant status	Treatment W+	N+	WN+	WN-
Matured*	71.0b	47.1bc	23.8c	97.0a
Dead	1.6	4.3	44.0	0.0
Failed to flower	11.3	44.3	28.6	0.0
Toppled	0.0	1.4	1.2	0.0
Broken	16.1	2.9	2.4	3.0

*Means followed by the same letter (s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

5.3.2. Effect of weevils and nematodes on the vegetative growth of plantain.

Results on the effects of weevils and nematodes on the vegetative growth of plantain obtained from plants that reached maturity is shown in Table 5.3.2.1. (Appendices 8 - 18). The results indicate that weevil and nematode infestation had a significant effect on the growth of the plants. Among the infested plants the sole weevil (W+) treated plots produced plants whose growth were closest to the growth characteristics exhibited by the control plants. This was obvious especially in the height and girth of the plants as well as the width of the seventh youngest leaf. Growth of plants in this treatment was, however, significantly reduced compared with the control with respect to other parameters such as the number of leaves, length of the seventh youngest leaf, number of suckers, height of the tallest sucker, the number of roots in 20 cm^3 volume of soil and corm diameter.

The nematode infested plants exhibited poor vegetative growth compared to that of the control. The results thus indicate a significant difference between the means of these two treatments in all the growth parameters except the number of the leaves on the tallest sucker. It was also evident from the results that the combined weevil and nematode infested plots produced plants whose growth were the poorest. Plants under this treatment were significantly shorter and also had a smaller girth than those from the other treatments. In addition, most of them supported less than 13 leaves at flowering and the mean number of roots recorded was approximately half the number compared with the control treatment.

At harvest all the treatments recorded a decrease in the number of leaves from the number that was observed at flowering, thus suggesting that leaf production does not continue beyond flowering. In spite of this phenomenon, the number of leaves retained by the control treatment was significantly higher than those found on the nematode and the combined weevil and nematode treatments. The combined weevil and nematode infested plants in particular, lost about 50% of their leaves between flowering and harvest.

The diameter of corms of the mother plants measured at harvest also showed that plants from the control treated plots produced significantly larger corms than those infested with nematodes and combined weevil and nematodes. Similarly, the corms associated with the sole weevil and sole nematode infested plants were also significantly larger than those observed on the plants from the combined weevil and nematode infested plots.

Table 5.3.2.1 Effect of weevils and nematodes on the vegetative growth of plantain

Growth Parameter	Treatment W+	N+	WN+	WN-
Number of leaves at flowering	14.6b	14.2b	12.7c	16.1a
Number of leaves at harvest	10.7ab	9.6bc	6.4c	13.2a
Plant girth (cm)	42.1ab	41.2bc	39.9c	42.5a
Plant height (cm)	272.0ab	266.2b	262.9c	278.7a
Length of seventh youngest leaf (cm)	182.2b	178.1b	168.6c	190.0a
Width of seventh youngest leaf (cm)	72.9ab	70.6b	69.9b	76.3a
Number of suckers	7.3b	6.5b	6.2b	9.5a
Tallest sucker height (cm)	75.5b	77.4b	74.6b	99.1a
Tallest sucker leaves (no.)	1.9a	1.4a	1.2a	2.4a
Number of roots per 20 cm^3 soil	19.4b	15.8bc	12.2c	24.2a
Corm diameter (cm)	21.2b	20.0b	14.7c	23.0a

Means in the same row followed by the same letter (s) are not significantly different according to Duncan's multiple range test ($P < 0.05$)

5.3.3 Nematode species found in the root tissues of the plantain cultivar Apantu-Pa at flowering and harvest.

Four nematode species namely; *Meloidogyne* sp., *Radopholus similis*, *Helicotylenchus multicinctus* and *Pratylenchus coffeae* were identified in the roots of the plants during flowering (Table 5.3.3.1). *Pratylenchus coffeae* was observed in all the samples often at high densities. Densities of *Helicotylenchus multicinctus* and *Meloidogyne* sp. on the other hand were observed to be moderate and were not observed in all samples. The density of *R similis* was very low and the occurrence was localised as it was found only in one plant from a plot treated with both weevil and nematodes.

Table 5.3.3.1. Density range of nematode species encountered on the plantain cultivar Apantu-Pa at flowering and harvest

Nematode species	Number in 100 g root sample	
	Flowering	Harvest
Meloidogyne sp.	9 -2,833	2 -5,923
Radopholus similis	0 - 522	0
Helicotylenchus multicinctus	0 - 1,454	0 - 858
Pratylenchus coffeae	707 - 112,652	344 - 202,678

At harvest, the plant infested with *Radopholus similis* was not available for sampling because it was uprooted due to viral infection. The other nematode species observed at flowering were encountered in all the roots sampled. With the exception of *Helicotylenchus multicinctus*, densities of the other nematodes (*P coffeae* and *Meloidogyne* sp.), increased between flowering and harvest.

5.3.4 Effect of the various treatments on the density of the dominant nematode species *Pratylenchus coffeae* at flowering and harvest in plantain roots.

A density comparison between the various treatments for the dominant nematode species *Pratylenchus coffeae* is shown in Table 5.3.4.1 (Appendices 19 - 20). At flowering, mean density of this nematode in the roots of the combined weevil and nematode treated plants was significantly higher than the other treatments. Similarly, the sole nematode treatment also had a significantly higher number of *P. coffeae* than the control and sole weevil treatments. The results, however, indicate that, nematode densities in the sole nematode and the combined weevil and nematode treatments were not significantly different. At harvest, however, the density of *P. coffeae* in the combined treatment was significantly higher than in the sole nematode treatment. In addition, the densites in these treatments had more than doubled between flowering and harvest. The control and sole weevil treated plants on the other hand, had a very low population of *P. coffeae*. The treatments were, not significant different in their mean densities in

Table 5.3.4.1 Numbers of the dominant nematode species, *Pratylenchus coffeae*, in 100 g root tissue of plantain at flowering and harvest

	Treatment			
Time of assessment	W+	N+	WN+	WN-
Flowering	1,172b	76,982a	112,652a	704b
Harvest	707c	153,348b	202,678a	344c

Means in a row followed by the same letter(s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

5.3.5. Effect of weevils and nematodes on the root health of plantain at flowering

The health status of the primary roots as shown in Table 5.3.5.1 (Appendices 21 - 22) was significantly affected by the weevil and nematode infestations. The results show that a very high percentage of functional roots was recorded from the control treatment at flowering. Compared to the control, the combined weevil and nematode, and sole nematode infestations, significantly reduced the percentage functional roots to 70.0% and 85.4% respectively. Among the infested plants, the sole weevil treatment recorded the highest number of functional roots (95%) and was therefore the only treatment whose percentage functional roots did not differ significantly from the control.

It was also observed that the functional roots from the control and weevil treated plants had very low levels of necrosis. The means of the two treatments were significantly lower than those scored in the roots from the sole nematode and combined weevil and nematode treatments. Comparison between the sole nematode and combined weevil and nematode treatments, however, showed that, the functional roots from the combined treatment were severely infested and therefore had a significantly higher necrotic index than those from the sole nematode infestation.

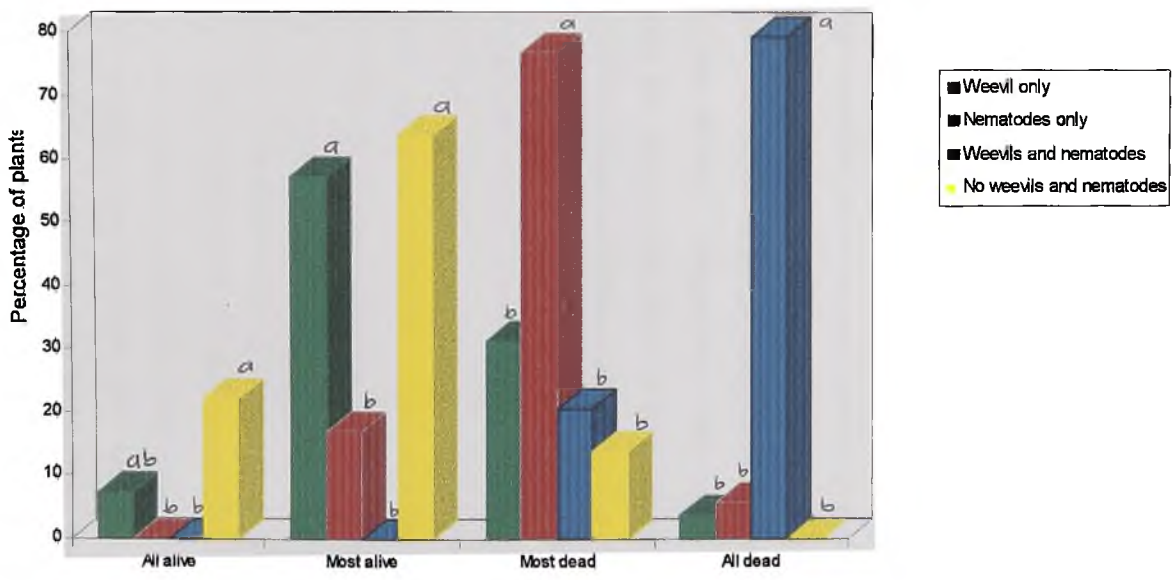
Table 5.3.5.1 Health status of primary roots at flowering

	Treatment			
Primary roots	W+	N+	WN+	WN-
Percentage functional	95.0ab	85.4b	70.0c	99.4a
Root necrosis (%)	3.8c	70.8b	92.0a	1.6c

Means in a row followed by the same letter(s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

Studies on the health status of feeder roots from the four treatments as shown in Figure 5.3.5.1 (Appendix 23) indicates that 7.4% and 22.2% of plants from the sole weevil and control plants respectively, had all their feeder roots alive at flowering. In contrast, no plant from the sole nematode or combined weevil and nematode treatments had all feeder roots alive at flowering. The percentage number of plants that had most of their feeder roots alive was also very high in the control followed by the sole weevil treatment. No significant difference was observed between these two treatments. The sole nematode treatment however recorded the lowest while none of the plants in the combined treatment was found in this category. Furthermore, a significantly higher percentage (77.0%) of plants from the sole nematode treatment had most of their feeder roots dead whereas almost 80.0% of those from the combined nematode and weevil treatment had all their feeder roots dead.

Figure 5.3.5.1 Effect of weevil and nematode infestation on the health status of feeder roots on the mothe at flowering



Health status

Bars sharing common letter(s) are not significantly different
(P < 0.05) Duncan's multiple range test

5.3.6 Effects of weevil and nematode infestation on the root health of the youngest sucker

Health evaluation of the primary roots of the suckers as shown in Table 5.3.6.1 (Appendices 24 - 29) revealed that no dead roots were observed on the control treated plants. It was also evident that the majority of roots from the sole weevil treated plants were functional. Compared to the control and sole weevil infestation, the nematode and combined weevil and nematode infestations significantly decreased the number of roots. In addition, these treatments significantly reduced the percentage functional roots obtained from the suckers to 80.7% and 72.7% respectively. It was also observed that, the entire cortex of all the roots from the combined weevil and nematode infested plants were necrotic. This phenomenon was also observed in most of the roots from the sole nematode treated plants. Invariably, the necrotic indices in the functional roots from the two treatments were significantly higher than those observed in the control and weevil treatments. The difference between the sole nematode and combined weevil and nematode treatments was also significant with the combined weevil and nematodes plants scoring over 90%.

Nematode damage in the form of small and large lesions were also observed on the corms of the suckers. Although, both types of lesions were present on the suckers from all the treatments, the control and sole weevil treatments recorded significantly lower numbers. The percentage of small lesions observed on corms with weevil and nematode infestation did not differ significantly from those with sole nematodes infestation. The percentage large lesions on the combined weevil and nematode treatment was however, significantly higher and about twice the value recorded on the sole nematode treatment.

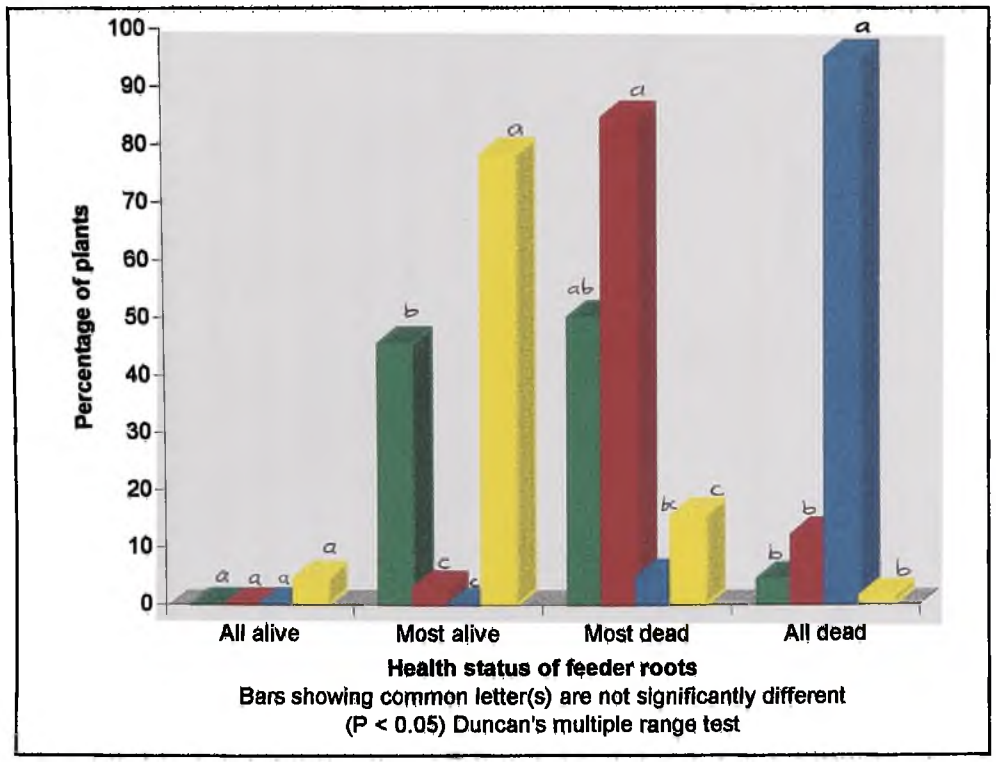
Table 5.3.6.1. Effect of weevils and nematodes on the root health of the youngest sucker

Parameters	Treatment			
	W+	N+	WN+	WN-
Nos. of roots	19.0b	16.9c	11.0d	27.8a
Nos. of root base	22.7b	20.8b	15.3c	28.3a
Roots functional (%)	99.8a	80.7b	72.7b	100.0a
Root necrosis (%)	2.6c	79.5b	92.5a	0.4c
Small lesions (%)	2.2b	12.8a	18.2a	0.4b
Large lesions (%)	4.1c	18.2b	37.9a	0.2c

Means in a row followed by the same letter(s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

Figure 5.3.6.1 (Appendix 30) shows the health status of the feeder roots on the youngest sucker at harvest. Feeder roots observed on the control treated suckers had a better health status than those produced by suckers from the other treatments; apart from the control, none of the plants from the other treatments had all its feeder roots alive. In addition, a higher percentage of about 78 % of the suckers from the control had most of their feeder roots alive while only 2 % of the plants had all roots dead. Among the infested plants, however, those from the sole weevil treatment produced feeder roots with the best health status. It was the treatment that recorded the highest percentage (45 %) of plants with most of their feeder roots alive as against 3 % and 0 % for the sole nematode and combined weevil and nematode treatments respectively. The results also showed that 85% of plants from the sole nematode treatment had most of their feeder roots dead as compared to 17% and 50% of the plants from the control and sole weevil treatments. A significant proportion (95.0%) of the suckers from the combined weevil and nematode treatment on the other hand, had all their feeder roots dead while the remaining 5% had most of theirs dead.

Figure 5.3.6.1 Effects of weevil and nematode infestation on the feeder roots of the youngest sucker at harvest



Bars showing common letter(s) are not significantly different ($P < 0.05$) Duncan's multiple range test

5.3.7 Severity of weevil damage on the corms of the youngest sucker at harvest

Table 5.3.7.1 (Appendices 31 33) shows the extent of corm damage due to weevils observed on the youngest suckers attached to the mother plants It was observed, that all the suckers from the combined weevil and nematode treatment were attacked. This was in contrast with the control where none of the plants showed any sign of damage. The results also showed that 3 % of the suckers from the sole nematode treatment had slight damage. It was, however, evident that the severity of weevil damage was higher in the presence of nematodes and weevils than in the presence of either pest. 95% of the total number of plants observed from the combined treatment, were severely damaged as compared to 36.4% recorded for the sole weevil treatment.

Table 5.3.7.1. Extent of corm damage due to weevils on the youngest sucker

Parameters	Treatment W+	N+	WN+	WN-
Suckers with no damage (%)	22.7b	97 0a	0.0c	100 0a
Suckers with slight damage (%)	40.9a	3.0b	5.0b	0.0b
Suckers with severe damage (%)	36.4b	0.0c	95.0a	0.0c

Means in a row followed by the same letter(s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

5.3.8 Effects of weevil and nematode infestations on weevil density, and corm damage of plantain

Figure. 5.3.8.1 (Appendix 34) shows the number of weevils per treatment at monthly intervals for six months after their introduction onto the plants. The weevil and nematode treatment recorded the highest numbers in all cases. Even though no weevil was introduced onto the sole nematode and control plots, some weevils were encountered on the plants in these plots. The weevil population declined between November and March 1996 as a result of a brief spell of drought during that period.

Figure 5.3.8.1 Effect of weevils and nematode infestation on the number of weevil per month

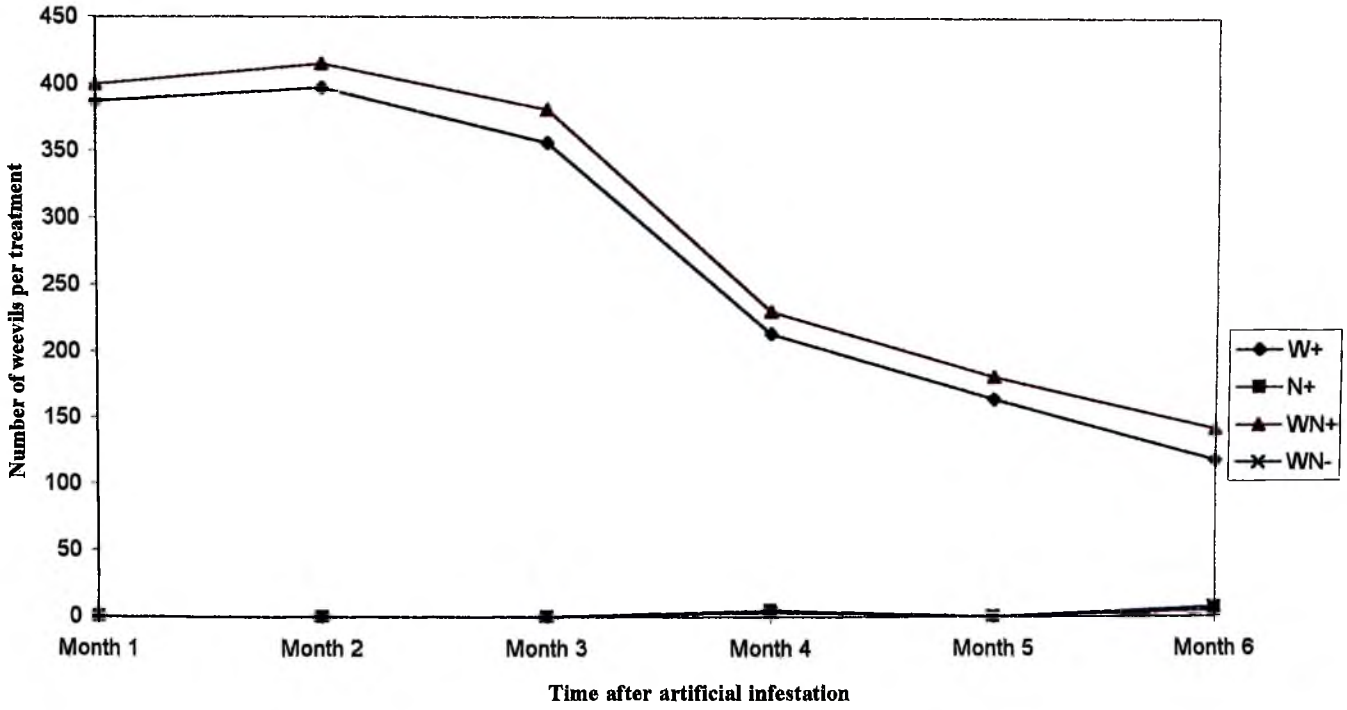


Table 5.3.8.1 (Appendices 35 37) shows the peripheral and cross-sectional damage of corms of harvested plants under weevil and nematode infestations. Observations made on the corms during weevil damage assessment revealed that with the exception of the control, weevil damage (both peripheral or cross-sectional) were recorded on all treatments. Analyses of the data on corm damage also revealed that weevil damage observed on the periphery of the plants infested with both weevils and nematodes was significantly higher and about twice the damage recorded on the plants which were under sole weevil infestation. The cross-sectional damage on the other hand was about four times greater. The data also suggests that a high incidence of external damage is a sure indication that the internal portions have also been attacked.

Table 5.3.8.1 Effect of weevils and nematodes on the damage of plantain corms at harvest

	Treatment			
Corm	W+	N+	WN+	WN-
Peripheral damage (%)	17.4b	0.7c	33.6a	0.0c
Cross-sectional damage (%)	5.3b	0.4c	20.7a	0.0c

Means in a row followed by the same letter(s) are not significantly different according to Duncan's multiple range test ($P < 0.05$).

5.3.9 Effect of combined damage of weevils and nematodes on mother plant and youngest sucker

It was observed that damage to the corms of the mother plants from the combined weevil and nematode infested plots was heavy. Similarly, a very high percentage of the suckers from these plants, were associated with high nematode damage in the form of small and large lesions. Observation on the corms of the mother plants and the associated suckers from the WN+ also revealed that portions with severe weevil damage had no root bases. Virtually no roots were found in such highly damaged areas of the plants.

5.3.10 Effect of weevil and nematode infestation on the yield characteristics of plantain

Table 5.3.10.1 (Appendices 37 43) shows the effect of weevil and nematodes on yield parameters of plantain. The results show that more than 40 fingers per bunch were produced on the average by the plants from the control treatment. The infested plants on the other hand, showed a decreasing trend in the mean number of fingers obtained from each bunch with the combined weevil and nematode treatment recording the lowest (approximately 50 % compared to the control). It was also observed that the individual effect of weevils and nematodes did not significantly affect the number of fingers produced. Similarly, the number of hands per bunch was not significantly affected by the individual weevil and nematode treatments.

Analyses of the data on fruit circumference and length showed that, neither weevil nor nematode occurring alone or together, had significant effect on the finger size of plantain. The middle finger weight was however, reduced significantly by the effect of the occurrence of both nematodes and weevils compared with the control.

Bunch weight was significantly affected by the treatments. The control treatment produced the heaviest bunches with an average weight of

approximately 13 kg. This was significantly higher than the bunch weight associated with the nematode and combined weevil and nematode treatments. Similarly, the average bunch weight obtained from the sole weevil treated plots was also significantly higher than that recorded from the sole nematode and combined weevil and nematode treatments. The mean plant yield per hectare also varied significantly among the treatments. The yield per hectare, which was obtained by multiplying average plant yield by the number of plants in one hectare (1667 according to the spacing used in this experiment), was invariably high for the control. Compared to the control, the sole weevil and nematode infestations reduced the yield by 34.8 % and 63.7 % respectively, whereas the combined weevil and nematode infestation further reduced it by 85.1 % to give a very low yield.

Table 5.3.10.1 Effect of the weevils and nematodes on yield parameters of plantain

Parameter	Treatment W+	N+	WN+	WN-
[a] Number of fingers	26a	32.8ab	21.5b	40.9a
[a] Number of hands	6.9a	6.8a	4.5a	7.3a
[a] Middle finger length (cm)	24.9a	22.1a	17.0a	25.3a
[a] Middle finger circumference (cm)	14.5a	12.7a	10.0a	14.6a
[a] Middle finger weight (g)	281.5ab	224.5b	167.6b	282.4a
[a] Bunch weight (kg)	11.1a	9.4b	7.6c	12.8a
[b] Plant yield (kg)	7.9b	4.4c	1.8d	12.5a
[b] Yield per hectare (t / ha)	13.2b	7.3c	3.0d	20.8a

Means in the same row followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$).

[a] Treatment means derived from plants that reached maturity

[b] Treatment means derived from all data plants irrespective of whether they reached maturity

5.3.11 Regressions of average plant yield against number of roots at flowering and harvest

Figures 5.3.11.1 and 5.3.11.2 show the relationship between yield of plantain and number of roots of the plants at flowering and harvest. Approximately half of the observations in Fig. 5.3.11.1 are on the line of best fit whilst the other half are moderately scattered along a linear trend of increasing yield with number of roots. In Fig 5.3.11.2, three-quarters of the observations lie on the regression line. The results also show a positive and highly significant (P = 0.05; Appendices 44 and 45) relationship between number of roots and plant yield

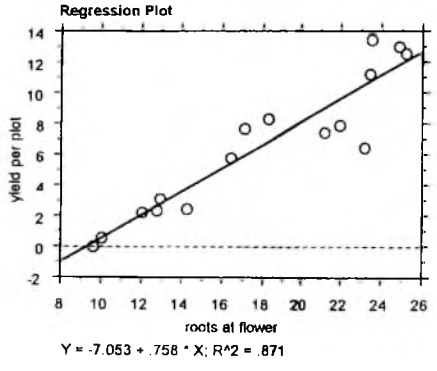


Figure 5.3.11.1

Relationship between yield and number of roots of plantain at flowering.

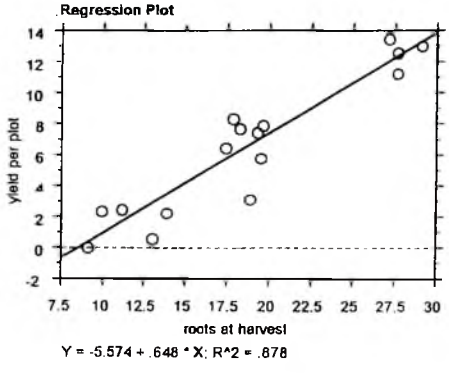


Figure 5.3.11.2

Relationship between yield and number of roots of plantain at harvest.

R^2 values were relatively high indicating that the relationships were adequately explained by the given models: Y=-7.053+.758x at flowering and Y=-5.574+.648x at harvest.

5.3.12 Regressions of average yield of plantain against necrotic index of roots at flowering and harvest

Regression analyses between yield and necrotic index of roots at flowering and harvest as indicated in Figures 5.3.12.1 and 5.3.12.2 showed that yield decreased with increasing necrotic index in plantain roots. A negative and highly significant relationship ($P = 0.05$; Appendices 46 and 47) was produced between yield and the necrotic indices of the roots at flowering and harvest.

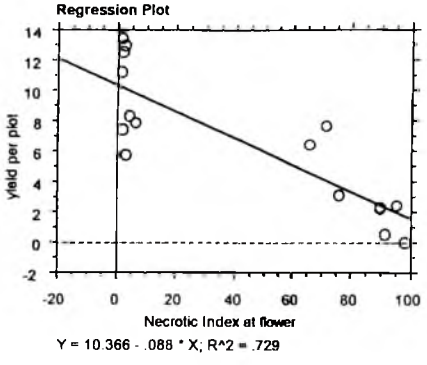


Figure 5.3.12.1

Relationship between yield and necrotic and index roots of plantain at flowering.

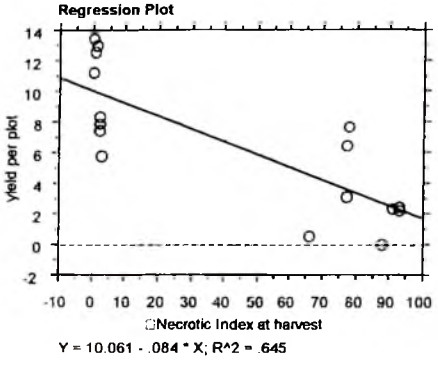


Figure 5.3.12.2

Relationship between yield necrotic index of roots of plantain at harvest

R^2 values were relatively high indicating that the relationships were adequately explained by the given models: Y=10.366-0.88x at flowering and Y=10.061-.084x at harvest.

5.4 DISCUSSION

The effect of weevil and nematode infestation on the growth and yield of plantain obviously, had a tremendous impact on the various parameters measured. One important observation was that, a huge percentage of the plants under the combined weevil and nematode treatment died compared to the other treatments. Consequently more than 75 % of the plants under this treatment, failed to reach maturity. This was thus a massive contribution to the yield loss / ha figure recorded for this treatment.

The high incidence of dead plants encountered on this treatment (about 10 fold increase) compared to the other treatments was due to the devastating effect of the combined damaging activities of both weevils and nematodes on the plants at the sucker stage (Froggatt, 1925 ; Franzman, 1972 and Spiejer, *et al.*, 1993). The early infection and faster multiplication rate of nematodes in the roots of the suckers (Sarah, 1989) might have resulted in the release of semio-chemicals by these plants which according to Budenburg *et al.* (1993), attracted the female weevils present and induced them to lay eggs. Since the plants at this stage of growth had smaller corms, it is possible that, the central cylinder was easily attacked by the larvae whose feeding and tunnelling activity might have destroyed the apical meristem leading to the death of the suckers. The presence of one or two adults and some larvae in the corms of most of the dead plants confirms this speculation.

The effect of this treatment was equally devastating on the plants that reached maturity. Plant performance as compared to the ones from the control and weevil treatments was very poor. This is partly because more nematodes (particularly *Pratylenchus coffeae*) were encountered on these plants. Thus nematode related damage such as high percentage necrosis, high percentage dead roots and the very poor health status of the feeder roots of both mother plants and suckers, were more pronounced on these plants. Moreover, plants under this treatment also had high weevil infestation whose larvae, inflicted severe damage to the corms.

The higher survival rate of eggs and larvae in such nematode infested corms has been reported (Speijer *et al.*, 1993) as a major factor responsible for enhancing weevil damage on infested plants than the uninfested ones. Several reports (Froggat, 1924; Franzman, 1972; Wright, 1977; Ittyeipe, 1986) have shown that, severe weevil damage to the corm also leads to the severing of the vascular strands in the corms cortical tissue as well as depletion of the food stored in the corm. These activities of the larvae thus accounted for the very low number of roots and comparatively smaller corm size associated with the plants from the combined weevil and nematode treated plots.

The very high nematode infestation of the roots of these plants could however, be due to the fact that, the severe weevil infestation resulted in the severe larvae tunnelling which then led to the production of much weaker corms (Wright, 1977). Such weaker corms probably gave rise to less healthier roots characterised by thin cell walls. This invariably, might have increased the susceptibility of the roots to the nematodes as well as increased their infectivity rate.

The resultant effects of these devastating damage due to weevils and nematodes, might possibly have accounted for the highly degraded root system of the parent plants and the youngest suckers attached to them. This invariably interfered with nutrient uptake and absorption from the soil and the subsequent translocation of food materials from the leaves to the corms. Consequently fruit formation and filling were thus affected (Speijer *et al.*, 1994). Since these parameters (fruit formation and filling) are functions of bunch weight (Ndibizu and Okafor, 1986) it was therefore obvious that plants from this treatment would produce much smaller bunches compared to the other treatments or no bunches at all as observed in many cases.

The sole nematode infestation also affected growth and yield of the plant. On per hectare basis, this pest reduced the yield of plantain by 12.7 tonnes and also caused a 26.6 % reduction in bunch weight compared to the control. The main cause of yield reduction was due to the large percentage of plants that failed to flower and thus did not reach maturity, as well as smaller bunch

weight. *Pratylenchus coffeae* which occurred in huge numbers, might have greatly accounted for the observed nematode effects. Plantains have been quoted (Pinochet and Rowe, 1978) to be pre-host to *Pratylenchus coffeae* The high pathogenicity of this nematode (Schill *et al.*, 1996) due to its ability to secrete specific enzymes permitted an easy penetration and feeding of the plantain roots (Pinochet and Rowe, 1978). Thus the extensive lesions associated with this damage (Blake, 1972), might have resulted in the massive destruction of the primary roots and thus reduced root number (Spiejer and Sikora, 1991).

The high density of *Pratylenchus coffeae* thus affected the yield directly through a reduction in the number of roots and indirectly through the severe necrosis encountered as shown in the regressions. The severe nematode infestation might have also caused a reduction in the life span of the secondary roots as well as enhance subsequent fungal rotting. This condition of the roots according to Speijer and Sikora (1993), also affects the productivity of plantain leading to a consequent yield loss.

There was a reduction in the number of *Helicotylenchus multicinctus* at harvest. It is possible that this nematode which is only capable of inciting discrete and relatively shallow necrotic lesions (Blake, 1972) was displaced by *Pratylenchus coffeae*. The displacement might have occurred as a result of the fact that, *Pratylenchus coffeae* which occurred in large numbers was more pathogenic (Schill *et al.*, 1996). In addition, the ability of this nematode to secrete specific enzyme that permit root penetration and feeding (Pinochet and Rowe, 1978) might have enabled it to colonise new cells in the roots at the expense of *Helicotylenchus multicinctus*.

Although the effect of weevil infestation on plant growth was not as dramatic as for the other infestations, there was still a yield reduction of 7 t / ha compared to the control, as well as a 12.8 % reduction in bunch weight. Yield loss under this treatment was due to the plants not reaching maturity as well as the smaller bunch weight that was encountered. Compared to the 25% yield loss reported by Gorenz (1963), and 85% reported by Rukazambuga (1996), a yield loss of 34.8% encountered in this experiment suggests that the pest status

of the banana weevil cannot be overemphasised. This could be realistic to field situations since a look at the data from experiment 1 showed that it is possible to get 10 weevils per plant

The presence of banana weevil alone affected the growth and yield of plantain because most of the symptoms commonly associated with weevil damage such as: severe larvae tunnelling and its associated reduced sucker and root productivity (Hill, 1986: Wright 1977), smaller corm size as a result of the reduction in the food storage capacity of the rhizome (Froggat, 1924: Franzman 1972), small number of fingers and hands with the associated lower bunch weight and yield (Haarer, 1964; Franzman, 1972. Gorenz, 1963, and Speijer *et al.*, 1994) were recorded in this treatment Plants under this treatment in addition to the natural infestation, were infested with 5 females and 5 males each, the damage of 17.4% and 5.3% recorded on the periphery and cross-sectional faces of the corms respectively, might have affected them so much as to exhibit the symptoms mentioned above. Compared to the combined weevil and nematode treatment the weevil treatment performed better both vegetatively and reproductively. This was probably because most of the damage occurred on the outer cortex than in the central cylinder tissue. Borer attack of this nature (Otsmark, 1974) slightly affect growth and productivity of the infested plants. It could also be possible that, the comparatively low nematode infestation on such plants had little effect on the root system hence nutrient uptake and absorption might have been less affected resulting in the enhancement of growth and development of the plants. The resultant large corm size associated with such plants compared to those of the combined weevil and nematode treatment could have posed a morphological constraint to the weevil attack. Thus corm damage was mostly restricted to the outer surface whiles ensuring that the inner central cylinder tissue which houses the apical meristem was prevented from severe infestation.

A report by Ittyeipe (1986), confirmed that large corm size affords a survival value to the plants as it prevents the apical meristem from complete destruction that might result in the reduction of growth and development of the plant. Another reason that might also account for the comparatively lower

effect of the sole weevil damage on the plants was that, since this experiment evaluated the treatment effects within the first crop cycle, it is possible that the gradual damage on the sole weevil treated plants could not reach the stage where plant performance would have been affected. Froggat (1924), confirmed this by mentioning that, the actual reduction of plant productivity directly attributable to borer infestation is more often than not in the nature of gradual, rather than sudden decrease due to the slow but steady undermining of the vitality of the parent plant. This could therefore, mean that plants in the first year are more likely to escape the effect of severe weevil infestation than the their followers in the ratoons. This was observed by Afreh-Nuamah (1993) who reported that weevil damage to the corm in the first year of growth has relatively slightly effect on the growth and development of plantain

It could also be possible that the comparatively low damage encountered on the weevil treated plants was due to the fact that some of the female weevils were attracted to the plots infested with both nematodes and weevils by virtue of the higher amount of volatile produced by the plants in those plots as was observed by Budendurg *et al.*, (1993).

Unlike the plants from the weevil treatment, those from the nematode treated plots generally exhibited less vigorous vegetative and reproductive growth than those from the control treatment. This might be due to the fact that, the level of root infestation and damage by nematodes, according to Vilardebo (1976) begin as soon as the plants started developing roots. Since the attack started that early, it is possible that it might have increased as the plant approached flowering resulting in high severity of primary root necrosis (Table 5.3.5.1) and associated poor health status of the feeder roots (Figure 5.3.5.1). Another reason for the comparatively poor performance of plants from the sole nematodes plot than those from the control and even the weevil treated plots was the further degradation of the root system. This occurred when the nematode damage, paved the way for the rapid colonisation by a host of unspecialized fungal pathogens whose high invasive potential (Pitcher, 1965), drastically affected the health status of both primary and secondary feeder roots. Invariably, the function of the roots system which involved

nutrient uptake and absorption was also affected to the extent that most of the growth and yield parameters measured were comparatively lower than what was observed for the control and sole weevil treatments.

CHAPTER SIX

CONCLUSION

This study of the effects of weevil and nematode infestation on the growth and yield of plantain has really unravelled the importance of the these pests on plantain in Ghana. The first experiment showed that weevil infestation and corresponding damage of plantain in the field starts at the early stage of growth and increase gradually as the plants develop shade providing features that can protect the insects. Experiment 2 also showed that under high population pressure when infestation starts very early the growth and development of the plants would be adversely affected and this could lead to 100% crop failure before maturity.

The main yield loss trial however, showed that, the occurrence of both weevils and nematodes in high densities will inevitably raise losses to levels above 85% in plantations where effective control is not exercised. When either pest is controlled leaving the other in contention, a yield loss of 34.8 % would still be encountered in the case of sole weevil infestation. Sole nematode infestation on the other hand, caused 63.7 % loss in yield.

This is an indication that, weevil and nematodes, could pose a major threat to plantain cultivation by reducing yields through massive crop losses and production of smaller bunches. In addition plantation life could also be affected through the effect on the availability of planting materials. Apparently, control of these pest whether alone or together is important.

Chemical control such as the use of Oftanol, Furadan and Nemacur, besides being hazardous to the farmer and environmentally unfriendly would raise production cost for those who do practice it. Alternatively, it would be advisable to abandon such heavily infested fields and allow to fallow for a period of at least three years. If increasing population pressure (the biggest problem confronting most countries in the West African sub-region (Karikari, 1971; INIBAP, 1986) might not permit old plantain fields to be left fallow for this period of time, then it would be beneficial to use planting materials that has

been made clean through paring and hot water treatment. The adoption of this control measure will have a great economic impact, especially for small and medium scale plantain producers in Ghana (Data from I.I.T.A on going project)

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APPENDICES

APPENDIX 1 ANOVA for mean number of female weevils collected per plant at the various stages of plant growth in 5 villages

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.89269919	0.31544987	40.29	0.0001
STAGE	2	1.76165516	0.88082758	112.51	0.0001
VILLAGE	4	0.13104403	0.03276101	4.18	0.0405
Error	8	0.06262831	0.00782854		
Corrected Total	14	1.95532750			
R-Square = 0.967970		C.V. = 6.400744			

APPENDIX 2 ANOVA for percent corm damage due to weevils at various growth stage of plantain in 5 villages

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.85447170	0.14241195	95.54	0.0001
STAGE	2	0.78057055	0.39028528	261.84	0.0001
VILLAGE	4	0.07390115	0.01847529	12.39	0.0001
Error	53	0.07899899	0.00149055		
Corrected Total	59	0.93347069			
R-Square = 0.915371		C.V. = 26.52726			

APPENDIX 3 ANOVA for number of roots of plantain cultivar Apantu - Pa harvested 31 days after infestation with banana weevil one, two, or three months after planting

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2264.81739130	452.96347826	118.89	0.0001
MONTH	2	1548.49239130	774.24619565	203.22	0.0001
TRTMENT	1	610.53260870	610.53260870	160.25	0.0001
MONTH*TRTMENT	2	105.79239130	52.89619565	13.88	0.0001
Error	86	327.65000000	3.80988372		
Corrected Total	91	2592.46739130			
R-Square = 0.873615		C.V. = 13.53234			

APPENDIX 4 ANOVA for fresh root weight of plantain cultivar Apantu-Pa harvested at 31 days after infestation with banana weevil one, two, or three months after planting

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	38530.73719565	7706.14743913	303.60	0.0001
MONTH	2	24676.48594565	12338.24297283	486.08	0.0001
TRTMENT	1	12148.60695652	12148.60695652	478.61	0.0001
MONTH*TRTMENT	2	1705.64429348	852.82214674	33.60	0.0001
Error	86	2182.93150000	25.38292442		
Corrected Total	91	40713.66869565			
R-Square = 0.946383		C.V. = 10.10353			

APPENDIX 9 ANOVA for effect of weevils and nematodes on the number of leaves of plantain at harvest

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	112.97665915	18.82944319	4.28	0.0258
TRTMENT	3	94.70094442	31.56698147	7.17	0.0093
REP	3	18.27571474	6.09190491	1.38	0.3095
Error	9	39.62862414	4.40318046		
Corrected Total	15	152.60528329			
R-Square = 0.740319		C.V. = 21.02716			

APPENDIX 10 ANOVA for effect of weevils and nematodes on the plant girth (cm)**of plantain**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	29.66222700	4.94370450	4.31	0.0251
TRTMENT	3	27.55022954	9.18340985	8.01	0.0066
REP	3	2.11199745	0.70399915	0.61	0.6230
Error	9	10.31984159	1.14664907		
Corrected Total	15	39.98206858			
R-Square = 0.741888		C.V. = 2.568169			

APPENDIX 11 ANOVA for effect of weevils and nematodes on the height (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	652.16422361	108.69403727	4.06	0.0300
TRTMENT	3	579.71964285	193.23988095	7.21	0.0091
REP	3	72.44458076	24.14819359	0.90	0.4776
Error	9	241.07899870	26.78655541		
Corrected Total	15	893.24322231			
R-Square = 0.730108		C.V. = 1.917235			

APPENDIX 12 ANOVA for effect of weevils and nematodes on the Length of seventh youngest leaf (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1074.82338768	179.13723128	15.09	0.0003
TRTMENT	3	950.46531888	316.82177296	26.69	0.0001
REP	3	124.35806877	41.45268959	3.49	0.0632
Error	9	106.85093591	11.87232621		
Corrected Total	15	1181.67432357			
R-Square = 0.909577		C.V. = 1.916894			

APPENDIX 13 ANOVA for effect of weevils and nematodes on the width of seventh youngest leaf (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	128.58768749	21.43128125	3.88	0.0341
TRTMENT	3	98.81506304	32.93835435	5.96	0.0160
REP	3	29.77262445	9.92420815	1.80	0.2177
Error	9	49.69976153	5.52219573		
Corrected Total	15	178.28744902			
R-Square = 0.721238		C.V. = 3.246576			

APPENDIX 14 ANOVA for effect of weevils and nematodes on number of suckers of the plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	116.80921384	19.46820231	7.97	0.0034
TRTMENT	3	99.62498187	33.20832729	13.60	0.0011
REP	3	17.18423197	5.72807732	2.35	0.1409
Error	9	21.97109298	2.44123255		
Corrected Total	15	138.78030682			
R-Square = 0.841684		C.V. = 19.76045			

APPENDIX 15 ANOVA for effect of weevils and nematodes on the tallest sucker height (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	11034.85563257	1839.14260543	3.16	0.0595
TRTMENT	3	9967.60768054	3322.53589351	5.70	0.0182
REP	3	1067.24795203	355.74931734	0.61	0.6249
Error	9	5243.37451738	582.59716860		
Corrected Total	15	16278.23014995			
R-Square = 0.677890		C.V. = 25.08849			

APPENDIX 16 ANOVA for effect of weevils and nematodes on the tallest sucker leaves of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	21.64426231	3.60737705	6.12	0.0084
TRTMENT	3	20.23330332	6.74443444	11.44	0.0020
REP	3	1.41095900	0.47031967	0.80	0.5256
Error	9	5.30617873	0.58957541		
Corrected Total	15	26.95044104			
R-Square =0.803113		C.V. = 27.36053			

APPENDIX 17 ANOVA for effect of weevils and nematodes on the number of plantain (mother plant) roots per 20 cm^3 soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	387.96867932	64.66144655	9.20	0.0020
TRTMENT	3	320.25056980	106.75018993	15.19	0.0007
REP	3	67.71810952	22.57270317	3.21	0.0760
Error	9	63.26524043	7.02947116		
Corrected Total	15	451.23391975			

R-Square	C.V.	Root MSE	ROOTS Mean
0.859795	14.80143	2.65131499	17.91256451

APPENDIX 18 ANOVA for effect of weevils and nematodes on the corm diameter of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	158.73526822	26.45587804	28.69	0.0001
TRTMENT	3	153.26834332	51.08944777	55.41	0.0001
REP	3	5.46692489	1.82230830	1.98	0.1881
Error	9	8.29849795	0.92205533		
Corrected Total	15	167.03376616			

R-Square = 0.950318 C.V. = 4.876832

APPENDIX 19 ANOVA for numbers of the dominant nematode species, *Pratylenchus coffeae*, in 100 g root tissue of plantain at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	39258180481.8824000	6543030080.3137300	11.76	0.0008
TRTMENT	3	37797862881.8222000	12599287627.2740000	22.64	0.0002
REP	3	1460317600.0602000	486772533.3534020	0.87	0.4895
Error	9	5008243593.2817000	556471510.3646330		
Corrected Total	15	44266424075.1641000			

R-Square = 0.886861 C.V. = 49.27080

APPENDIX 20 ANOVA for numbers of the dominant nematode species, *Pratylenchus coffeae*, in 100 g root tissue of plantain at harvest

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
M TRTMENT	3	130874636080.759000	43624878693.586600	1251.05	0.0001
REP	3	251394155.122762	83798051.707587	2.40	0.1350
model	6	131126030235.882000	21854338372.647100	626.73	0.0001
Error	9	313835805.204666	34870645.022741		
Corrected Total	15	131439866041.087000			

R-Square = 0.997612 C.V. = 6.614981

APPENDIX 2I ANOVA for effect of weevils and nematodes on the percentage functional root of plantain at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.73225693	0.28870949	7.94	0.0034
TRTMENT	3	1.42347625	0.47449208	13.06	0.0013
REP	3	0.30878068	0.10292689	2.83	0.0986
Error	9	0.32705372	0.03633930		
Corrected Total	15	2.05931065			

R-Square	C.V.	Root MSE	OK Mean
0.841183	18.32243	0.19062870	1.04041170

APPENDIX 22 ANOVA for effect of weevils and nematodes on the percentage root necrosis of plantain at flowering

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4.28994076	0.71499013	73.96	0.0001
TRTMENT	3	4.23618910	1.41206303	146.07	0.0001
REP	3	0.05375166	0.01791722	1.85	0.2079
Error	9	0.08700608	0.00966734		
Corrected Total	15	4.37694684			

R-Square	C.V.	Root MSE	RI Mean

APPENDIX 23 ANOVA for effect of weevils and nematodes on the health status of the secondary roots of plantain at flowering

a. Dependent Variable: ALLALIVE all alive

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.13469661	0.02244944	1.34	0.3404
TRTMENT	3	0.11874752	0.03958251	2.37	0.1467
REP	3	0.01594909	0.00531636	0.32	0.8123
Error	8	0.13373757	0.01671720		
Corrected Total	14	0.26843418			

R-Square = 0.501786 C.V. = 173.9931

b. Dependent Variable: MOSTALIV most alive

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.46210098	0.24368350	5.90	0.0126
TRTMENT	3	1.45044657	0.48348219	11.70	0.0027
REP	3	0.01165441	0.00388480	0.09	0.9612
Error	8	0.33064206	0.04133026		
Corrected Total	14	1.79274304			

R-Square = 0.815566 C.V. = 53.07202

c. Dependent Variable: MOSTDEAD most dead

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2.06956053	0.34492675	6.41	0.0098
TRTMENT	3	1.92980053	0.64326684	11.95	0.0025
REP	3	0.13976000	0.04658667	0.87	0.4977
Error	8	0.43077982	0.05384748		
Corrected Total	14	2.50034035			.

R-Square = 0.827712 C.V. = 51.16071

d. Dependent Variable: ALLDEAD all dead

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.42976199	0.23829367	7.62	0.0057
TRTMENT	3	1.36944452	0.45648151	14.59	0.0013
REP	3	0.06031747	0.02010582	0.64	0.6088
Error	8	0.25027069	0.03128384		
Corrected Total	14	1.68003268			.

R-Square = 0.851032 C.V. = 106.8097

APPENDIX 24 ANOVA for effects of weevil and nematode infestation on the nos. of roots of the youngest sucker

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	610.84918850	101.80819808	72.60	0.0001
TRTMENT	3	585.14377990	195.04792663	139.10	0.0001
REP	3	25.70540860	8.56846953	6.11	0.0149
Error	9	12.62005173	1.40222797		
Corrected Total	15	623.46924023			.

R-Square	C.V.	Root MSE	ROOTS Mean
0.979758	6.339444	1.18415707	18.67919405

APPENDIX 25 ANOVA for effects of weevil and nematode infestation on the root nos. of root base of the youngest sucker

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	323.44403614	53.90733936	20.18	0.0001
TRTMENT	3	298.68545289	99.56181763	37.27	0.0001
REP	3	24.75858326	8.25286109	3.09	0.0825
Error	9	24.04523511	2.67169279		
Corrected Total	15	347.48927126			.

R-Square	C.V.
0.930803	7.248923

APPENDIX 26 ANOVA for effects of weevil and nematode infestation on the functional (%) root of the youngest sucker

Dependent Variable: OK % functional roots

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.92528938	0.32088156	5.54	0.0116
TRTMENT	3	1.82860843	0.60953614	10.52	0.0027
REP	3	0.09668095	0.03222698	0.56	0.6570
Error	9	0.52161206	0.05795690		
Corrected Total	15	2.44690144			

R-Square = 0.786828 C.V. = 21.63804

APPENDIX 27 ANOVA for effects of weevil and nematode infestation on the root necrosis (%) of the youngest sucker

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	27151.76024067	4525.29337345	644.27	0.0001
TRTMENT	3	27100.49657210	9033.49885737	1286.11	0.0001
REP	3	51.26366857	17.08788952	2.43	0.1320
Error	9	63.21520255	7.02391139		
Corrected Total	15	27214.97544322			

R-Square	C.V.	Root MSE	RI Mean
0.997677	6.296232	2.65026629	42.09289383

APPENDIX 28 ANOVA for effects of weevil and nematode infestation on the small lesions (%) of the youngest sucker

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.06852990	0.01142165	7.51	0.0042
TRTMENT	3	0.06153721	0.02051240	13.49	0.0011
REP	3	0.00699269	0.00233090	1.53	0.2720
Error	9	0.01368845	0.00152094		
Corrected Total	15	0.08221835			

R-Square	C.V.	Root MSE	SMALLL Mean
0.833511	48.24454	0.03899921	0.08083653

APPENDIX 29 ANOVA for effects of weevil and nematode infestation on the large lesions (%) health of the youngest sucker

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.28248681	0.04708113	70.91	0.0001
TRTMENT	3	0.27896335	0.09298778	140.04	0.0001
REP	3	0.00352345	0.00117448	1.77	0.2229
Error	9	0.00597598	0.00066400		
Corrected Total	15	0.28846276			

R-Square = 0.979283 C.V. = 17.22020

APPENDIX 30 ANOVA for effect of weevils and nematodes on the health status of the secondary roots of plantain suckers at harvest

a. Dependent Variable: ALLALIVE all alive

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.01042261	0.00173710	1.64	0.2522
TRTMENT	3	0.00749766	0.00249922	2.36	0.1473
REP	3	0.00292495	0.00097498	0.92	0.4731
Error	8	0.00846471	0.00105809		
Corrected Total	14	0.01888732			

R-Square	C.V.	Root MSE	ALLALIVE Mean
0.551831	934.2558	0.03252827	0.00348173

b. Dependent Variable: MOSTALIV most alive

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2.03393307	0.33898885	18.52	0.0003
TRTMENT	3	2.02469428	0.67489809	36.86	0.0001
REP	3	0.00923879	0.00307960	0.17	0.9149
Error	8	0.14646948	0.01830869		
Corrected Total	14	2.18040255			

R-Square	C.V.	Root MSE	MOSTALIV Mean
0.932825	37.14381	0.13530959	0.36428574

c. Dependent Variable: MOSTDEAD most dead

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.61282361	0.26880393	2.57	0.1088
TRTMENT	3	1.33414295	0.44471432	4.25	0.0453
REP	3	0.27868066	0.09289355	0.89	0.4880
Error	8	0.83788418	0.10473552		
Corrected Total	14	2.45070779			

R-Square	C.V.	Root MSE	MOSTDEAD Mean
0.658105	81.42085	0.32362868	0.39747644

d. Dependent Variable: ALLDEAD all dead

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4.03683110	0.67280518	5.11	0.0192
TRTMENT	3	3.62839392	1.20946464	9.18	0.0057
REP	3	0.40843719	0.13614573	1.03	0.4283
Error	8	1.05412892	0.13176612		
Corrected Total	14	5.09096003			

R-Square	C.V.	Root MSE	ALLDEAD Mean
0.792941	94.82939	0.36299603	0.38278853

APPENDIX 31 ANOVA for effect of weevils and nematodes on the number of youngest sucker with no damage due to weevils

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6.79081580	1.13180263	55.25	0.0001
TRTMENT	3	6.69879925	2.23293308	109.01	0.0001
REP	3	0.09201656	0.03067219	1.50	0.2803
Error	9	0.18435980	0.02048442		
Corrected Total	15	6.97517560			

R-Square	C.V.	Root MSE	DAMAGE Mean
0.973569	18.94167	0.14312380	0.75560292

APPENDIX 32 ANOVA for effect of weevils and nematodes on the number of youngest sucker with slight damage due to weevils

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.51718218	0.08619703	14.91	0.0003
TRTMENT	3	0.48414095	0.16138032	27.91	0.0001
REP	3	0.03304123	0.01101374	1.90	0.1993
Error	9	0.05204054	0.00578228		
Corrected Total	15	0.56922272			

R-Square	C.V.
0.908576	58.49802

APPENDIX 33 ANOVA for effect of weevils and nematodes on the number of youngest sucker with severe damage due to weevils

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4.03553045	0.67258841	33.34	0.0001
TRTMENT	3	3.94532016	1.31510672	65.19	0.0001
REP	3	0.09021029	0.03007010	1.49	0.2820
Error	9	0.18155164	0.02017240		
Corrected Total	15	4.21708209			

R-Square	C.V.	Root MSE	DAMAGE Mean
0.956949	36.84680	0.14202959	0.38545972

APPENDIX 35 ANOVA for effects of weevil and nematode infestations on peripheral corm damage of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.33126305	0.05521051	130.86	0.0001
TRTMENT	3	0.32968058	0.10989353	260.48	0.0001
REP	3	0.00158248	0.00052749	1.25	0.3481
Error	9	0.00379705	0.00042189		
Corrected Total	15	0.33506011			

R-Square = 0.988668 C.V. = 14.39367

APPENDIX 36 ANOVA for effects of weevil and nematode infestations on cross sectional corm damage of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.12177396	0.02029566	96.67	0.0001
Error	9	0.00188958	0.00020995		
TRTMENT	3	0.12079016	0.04026339	191.77	0.0001
REP	3	0.00098380	0.00032793	1.56	0.2652
Corrected Total	15	0.12366355			

R-Square = 0.984720 C.V. = 18.40552

APPENDIX 37 ANOVA for effect of weevil and nematode infestation on the number of fingers of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	923.61833249	153.93638875	2.46	0.1091
TRTMENT	3	815.13481750	271.71160583	4.33	0.0377
REP	3	108.48351499	36.16117166	0.58	0.6446
Error	9	564.25118453	62.69457606		
Corrected Total	15	1487.86951701			

R-Square = 0.620766 C.V. = 24.14571

APPENDIX 38 ANOVA for effect of weevil and nematode infestation on the number of hands of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	29.53055897	4.92175983	2.50	0.1049
TRTMENT	3	18.97725880	6.32575293	3.21	0.0760
REP	3	10.55330017	3.51776672	1.79	0.2199
Error	9	17.73559374	1.97062153		
Corrected Total	15	47.26615271			

R-Square = 0.624772 C.V. = 2.11989

APPENDIX 39 ANOVA for effect of weevil and nematode infestation on the middle finger length (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	300.79148330	50.13191388	1.70	0.2266
TRTMENT	3	177.06599233	59.02199744	2.01	0.1837
REP	3	123.72549097	41.24183032	1.40	0.3045
Error	9	264.76100607	29.41788956		
Corrected Total	15	565.55248937			

R-Square = 0.531854 C.V. = 24.30450

APPENDIX 40 ANOVA for effect of weevil and nematode infestation on the middle finger circumference (cm) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	96.71456657	16.11909443	1.51	0.2780
TRTMENT	3	54.97772070	18.32590690	1.71	0.2332
REP	3	41.73684588	13.91228196	1.30	0.3326
Error	9	96.20227328	10.68914148		
Corrected Total	15	192.91683985			
R-Square = 0.501328		C.V. = 25.25095			

APPENDIX 41 ANOVA for effect of weevil and nematode infestation on the middle finger weight (g) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	47722.90821829	7953.81803638	2.60	0.0955
TRTMENT	3	36013.14236086	12004.38078695	3.93	0.0480
REP	3	11709.76585743	3903.25528581	1.28	0.3398
Error	9	27503.57354893	3055.95261655		
Corrected Total	15	75226.48176722			
R-Square = 0.634390		C.V. = 23.12831			

APPENDIX 42 ANOVA for effect of weevil and nematode infestation on bunch weight (kg) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	274.70663159	45.78443860	12.84	0.0006
TRTMENT	3	259.61453386	86.53817795	24.27	0.0001
REP	3	15.09209772	5.03069924	1.41	0.3021
Error	9	32.08989665	3.56554407		
Corrected Total	15	306.79652824			
R-Square = 0.895403		C.V. = 28.38708			

APPENDIX 43 ANOVA for effect of weevil and nematode infestation on plant yield (kg) of plantain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	274.70663159	45.78443860	12.84	0.0006
TRTMENT	3	259.61453386	86.53817795	24.27	0.0001
REP	3	15.09209772	5.03069924	1.41	0.3021
Error	9	32.08989665	3.56554407		
Corrected Total	15	306.79652824			
R-Square = 0.895403		C.V. = 28.38708			

APPENDIX 44 ANOVA for relationship between yield and number of roots of plantain at flowering.

Source	DF	Sum of squares	Mean square	F-Value	P-Value
Regression	1	259.337	259.337	94.427	<.0001
Residual	14	38.450	2.746		
Total	15	297.787			

Regression Coefficients

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	-7.053	1.457	-4..839		.0003
roots at flower.	.758	.078	.933		<.0001

APPENDIX 45 ANOVA for relationship between yield and number of roots of plantain at harvest

Source	DF	Sum of squares	Mean square	F-Value	P-Value
Regression	1	261.538	261.538	101.011	<.0001
Residual	14	36.249	2.589		
Total	15	297.787			

Regression Coefficients

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	-5.574	1.269	-5.574	-4.392	.0006
roots at harvest.	.648	.64	.937	10.050	<.0001

APPENDIX 46 ANOVA for relationship between yield and necrotic index of roots of plantain at flowering

Source	DF	Sum of squares	Mean square	F-Value	P-Value
Regression	1	217.052	217.052	37.638	<.0001
Residual	14	80.735	5.767		
Total	15	297.787			

Regression Coefficients

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	10.366	.867	10.366	11.950	.0001
Necrotic index at flower.	-.088	.014	-.854	-6.135	<.0001

APPENDIX 47 ANOVA for relationship between yield and necrotic index of roots of plantain at harvest

Source	DF	Sum of squares	Mean square	F-Value	P-Value
Regression	1	192.004	192.004	25.411	<.0002
Residual	14	105.783	7.556		
Total	15	297.787			

Regression Coefficients

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	10.061	.982	10.061	10.246	<.0001
Necrotic Index at harvest	.084	.017	-.803	-5.041	<.0001